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Scallop fishing area 29: Stock status and update for 2009

Zone de pêche 29 du pétoncle : état du stock et mise à jour pour 2009

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Abstract

This scallop fishery has taken place in the portion of Scallop Fishing Area (SFA) 29 west of longitude 65°30′W since 2001 and is currently conducted by two fleets: the Full Bay Fleet and a limited number of inshore East of Baccaro licence holders (i.e., East of Baccaro Fleet). During 2008, a total of 249 t (190 t Full Bay; 59 t East of Baccaro) was landed against a TAC of 250 t. The fishery in subareas A and E has been sporadic in the last two years and commercial catch rates in these areas appear to have increased from 2007 to 2008. In subarea B, commercial catch rates for the Full Bay fleet have declined by 19% since 2006, while the East of Baccaro fleet catch rates have remained stable. The Full Bay fleet commercial catch rates have been stable in subarea C over the last three years and the East of Baccaro fleet catch rates have increased from 2006 to 2008. Catch rates have been declining (31 to 34%) for both fleets in subarea D since 2005. Estimates from the combined daily commercial catch rate in 2007 and 2008 indicated that exploitation had decreased by up to one half in subarea B, remained stable in subarea C and possibly doubled in subarea D. Estimates were not possible for subarea A due to the small amounts of catch taken there. Catches of 1 year old scallops (shell heights $\leq$ 50 mm) in the 2007 survey were widely distributed with the highest densities in subarea A. With the possible exception of subarea D, these densities did not translate into high densities of two year olds in the 2008 survey. The survey index for commercial size scallops in subarea A indicated an increase in 2008 compared to 2007 but, given the patchy nature of the distribution of scallops in this subarea and the lack of recruitment observed over the time series, survey trends in subarea A may not reflect actual population trends. The survey index in subarea B has indicated a general decline in abundance since 2002 with an indication of little change in abundance after 2006. Recruitment continued to be low in this subarea. Since 2006, recruitment has continued to be low in subarea C with the Full Bay survey indicating a stable commercial size population and the East of Baccaro survey indicating increasing abundance over the same time period. The Full Bay survey index indicated an increase in the abundance of commercial size scallops from 2007 to 2008 in subarea D, while the East of Baccaro series showed a continued decline from 2005. Recruitment continued to be low in both series since 2005. Catch level recommendations for the 2009 fishery were based on the interpretation of trends in the catch rate, survey and exploitation time series; subarea A: 10–20 t, subarea B: 60–80 t, subarea C: 60–80 t and subarea D: $\leq$ 85 t. Bycatch of lobster by the SFA 29 scallop fishery in 2008 was estimated at less than 0.1% of the weight of lobsters landed by the Lobster Fishing Area (LFA) 34 lobster fishery in the SFA 29 area. The majority of the lobsters caught in the scallop fishery were released back into the water alive and uninjured.

Résumé

La pêche du pétoncle considérée ici se déroule dans la partie de la zone de pêche du pétoncle (ZPP) 29 située à l'ouest de la longitude 65° 30′ O depuis 2001; elle est actuellement pratiquée par deux flottilles, soit la flottille de la totalité de la baie et un nombre limité de titulaires de permis de pêche côtière pour l'est de Baccaro (flottille de l'est de Baccaro). En 2008, les débarquements totaux se sont chiffrés à 249 t (190 t pour la flottille de la totalité de la baie et 59 t pour les pêcheurs de l'est de Baccaro), par rapport à un TAC de 250 t. La pêche dans les sous zones A et E a été sporadique ces deux dernières années et les taux de prises commerciales dans ces eaux semblent avoir augmenté de 2007 à 2008. Dans la sous zone B, les taux de prises commerciales de la flottille de la totalité de la baie ont diminué de 19 % depuis 2006, tandis que les taux de prises de la flottille de l'est de Baccaro ont été stables. Dans la sous zone C, les taux de prises commerciales de la flottille de la totalité de la baie ont été stables au cours des trois dernières années et ceux de la flottille de la totalité de la baie ont augmenté de 2006 à 2008. Les taux de prises des deux flottilles ont diminué (de 31 à 34 %) dans la sous zone D depuis 2005. Il ressort des estimations du taux combiné de prises commerciales quotidiennes en 2007 et 2008 que l'exploitation a diminué de moitié dans la sous zone B, qu'elle est restée stable dans la sous zone C et qu'elle a peut-être doublé dans la sous zone D. Il n'a pas été possible d'établir des estimations pour la sous zone A, en raison de la faible quantité de prises capturées dans cette sous zone. Les prises de pétoncles de 1 an (hauteurs de coquille $\leq$ 50 mm) dans le relevé de 2007 étaient largement réparties, leurs plus fortes densités se trouvant dans la sous zone A. Sauf peut-être dans la sous zone D, ces fortes densités ne se sont pas traduites par des densités équivalentes de pétoncles d'âge 2 dans le relevé de 2008. En ce qui concerne les pétoncles de taille commerciale dans la sous zone A, l'indice du relevé dénote une hausse en 2008 par rapport à 2007, mais compte tenu de la répartition éparse des pétoncles dans cette sous zone et de l'absence de recrutement observée dans toute la série chronologique, les tendances du relevé dans la sous zone A ne reflètent peut être pas les tendances réelles de la population. Dans la sous zone B, l'indice du relevé dénote une baisse générale de l'abondance depuis 2002 et peu de changement à partir de 2006. Le recrutement continue d'être faible dans cette sous zone. Depuis 2006, le recrutement est resté bas dans la sous zone C; le relevé de la flottille de la totalité de la baie reflète un effectif stable de la population de taille commerciale et le relevé de la flottille de l'est de Baccaro une hausse de l'abondance pendant la même période. Le relevé de la flottille de la totalité de la baie dénotait une hausse de l'abondance des pétoncles de taille commerciale de 2007 à 2008 dans la sous zone D, tandis que le relevé de la flottille de l'est de Baccaro reflétait un déclin constant depuis 2005. Les deux relevés indiquent que le recrutement reste faible depuis 2005. Les recommandations sur les niveaux de prises dans la pêche de 2009 ont été fondées sur l'interprétation des tendances des séries chronologiques sur les taux de prises, les indices de relevé et l'exploitation. Elles sont de 10–20 t pour la sous zone A, de 60–80 t pour la sous zone B, de 60–80 t pour la sous zone C et de $\leq$ 85 t pour la sous zone D. Les prises accessoires de homard dans la pêche du pétoncle pratiquée dans la ZPP 29 en 2008 ont été estimées à moins de 0,1 % du poids du homard débarqué par les homardiers de la zone de pêche du homard (ZPH) 34 dans la ZPP 29. Les homards capturés dans la pêche du pétoncle ont été en majorité remis à l'eau vivants et indemnes.

Introduction

Scallop Fishing Area (SFA) 29 encompasses a very large inshore area inside the 12-mile territorial sea, from the south of Yarmouth (latitude 43°40′N) to Cape North in Cape Breton (Fig. 1). This report refers to only that portion of SFA 29 west of longitude 65°30′W continuing north to Scallop Production Area 3 at latitude 43°40′N.

Prior to 1986, the Full Bay Scallop fleet (FB) had fished in this area. Following the 1986 inshore/offshore scallop fishing agreement, fishing by the Full Bay fleet was restricted to north of latitude 43°40′N. A limited fishery by the Full Bay fleet was granted from 1996–98 in the northern portion of SFA 29 as defined above. Access was again granted to this fleet in 2001 with a full at-sea monitoring program, and under the condition that a post-season industry-funded survey would be conducted. Scallop fishers had consulted with lobster fishers in the area to deal with potential conflicts. Lobster by-catch was minimal in 2001 despite high scallop catch rates (for more details on the history of this fishery see Smith and Lundy 2002). Lobster bycatch continues to be monitored in this fishery.

In 2002, the Minister approved access to SFA 29 by the Full Bay fleet and inshore East of Baccaro (EoB) licence holders who are authorized to fish in SFA 29 west of longitude 65°30′W. SFA 29 inshore scallop licenses were historically restricted to the east of Baccaro Point (east of longitude 65°30′W). Five subareas within SFA 29 (A to E) were defined for the 2002 fishery based upon areas of similar densities of commercial size scallops in the 2001 survey (Fig. 1). These subareas were designed to provide flexibility in the allocation of catch and fishing effort for the 2002 fishery and have been retained as part of the fishing plan since then (Smith and Lundy 2002).

A three-year joint project agreement was signed in 2002 with the two fishing fleets, Natural Resources Canada, and Department of Fisheries and Oceans with all parties providing funds to conduct multi-beam acoustic mapping of the seafloor and other scientific work. Beginning in 2005, the annual research survey has incorporated the bottom type into its stratified design. Details on the multibeam project including a preliminary geological interpretation and analyses of the data in a fisheries science context are given in DFO (2006).

In 2008 an updated geophysical categorization of bottom type was developed based on all of the geophysical data (multibeam sonar bathymetry and backscatter strength, seismic reflection profiles, sidescan sonograms) and geological data (sea floor photographs and video, sediment samples). This categorization is presented here as a 1:50 000 scale map (Fig. 2, Todd et al. 2009). SFA 29 is located within the glaciated continental shelf of Atlantic Canada. Here, bedrock is overlain by widespread ice-contact sediment (Ic1, till), glaciomarine silt (Gm), and postglacial sand and gravel (Pg). Ice-contact sediment consists of a heterogeneous mixture of clay, sand, gravel and boulders of varying size and shape. Glaciomarine silt is poorly sorted clayey and sandy silt with some gravel. Postglacial sand and gravel consists of well-sorted sand, grading to rounded and subrounded gravel. Exposed bedrock areas were identified as being either igneous bedrock mantled with discontinuous sediments (Dg) or metamorphic bedrock (granite) mantled with discontinuous sediments (Є-Om). Mapped boundaries between sediment types are approximate. This new geophysical categorization was not available for the 2008 stock assessment but has been incorporated in to this year's analysis.

This report summarizes commercial fishery, research survey and observer data for the 2008 fishery and provides advice for the 2009 fishery. The scallop fishery in this area was last assessed in 2008 (Smith et al. 2008b).

Commercial fishery

The fishery management plan sets a 100 mm minimum shell height for retained scallops. In this report, scallops with shell height 100 mm and greater will be referred to as commercial size and 90–99 mm scallops will be referred to as recruits for the following year.

All subareas opened for the 2008 fishing season on June 23. Subarea D closed first (July 8 - FB, July 11 - EoB) with overruns of the total allowable catch (TAC) of 56% and 22% by Full Bay and East of Baccaro fleets, respectively (Table 1). The TACs for subarea C were also overrun (FB - 25%, EoB - 10%) and this subarea was closed to fishing on July 21 for the Full Bay fleet and on July 23 for East of Baccaro. Two closed areas within subarea B were instituted for both fleets in response to lobster bycatch reports on July 26 and August 2 before the whole area was closed to the Full Bay fleet on August 9. Subareas A and E were closed to the Full Bay fleet on August 21, and the TAC was not reached in these areas or in subarea B. The fishery in subareas A, B and E were closed on September 16 for the East of Baccaro fleet with the TAC not being reached in any of these areas. This closure was due to the overall TAC for subareas A to E being reached.

Commercial catch rate

Annual trends

The restructuring of the scallop commercial catch and effort database has been completed for all years in the department's Maritime Fishery Information System (MARFIS) database (2002–2008). This restructuring was necessary to get as accurate as possible estimates of daily catch rates (see Smith et al. 2008b).

The fishery in subareas A and E has been sporadic in the last two years and commercial catch rates in these areas appear to have increased from 2007 to 2008 (Fig. 3). In subarea B, commercial catch rates for the Full Bay fleet have declined by 19% since 2006 while the East of Baccaro fleet catch rates have remained stable. The Full Bay fleet commercial catch rates have been stable in subarea C over the last three years and the East of Baccaro fleet catch rates have increased from 2006 to 2008. Catch rates have been declining (31 to 34%) for both fleets in subarea D since 2005. Subarea D continues to have higher catch rates than the other subareas.

Vessel Monitoring Data (VMS)

Fishing patterns

The Vessel Monitoring System (VMS) is an automated method for collecting position and time at position information of vessels at sea. These data are typically used to monitor the

compliance of fishing in assigned fishing grounds; however, these data also have the potential to provide information on the spatial distribution of fishing.

VMS data were obtained from the DFO VMS database for years 2002 to 2008 for inshore scallop vessels that had a license to fish in SFA 29. For each year, only those records that fell within the time period of the SFA 29 fishing season were used. This dataset was also filtered to remove erroneous geographic records (records outside 70° to 63°W longitude and 42° to 46°N latitude).

Since VMS data do not indicate whether a vessel is fishing when its position is recorded, vessel speed was used to determine if fishing was in progress. Most vessels transmit their positions on an hourly basis, and speed was calculated from the distance travelled (great-circle distance) and time difference between successive VMS points from the same vessel for the same trip. Records with an associated speed greater than 0 knots and less than 4 knots were identified as 'fishing'. Fishing intensity maps were then generated from the filtered VMS data using the point density tool in ArcGIS[1]. This tool calculates a magnitude (number of 'fishing' VMS records) per unit area (sq km) that falls within a neighbourhood (circle with 1.75 km diameter) of each cell (250 m^2).

Fishing intensity (VMS records per sq km) was standardized to the highest fishing intensity values. For individual years the highest fishing intensity occurred in 2002, while for the cumulative fishing intensity the highest value was obtained from summing over 2002 to 2008.

For 2003, over 40% of VMS records were single records per day (Table 2). Due to the significant time lapse (> 4 hrs) between successive records from the same vessel for the same trip, it was not possible to confidently calculate speed for these records and these data were discarded. The sample size for 2003 is therefore significantly lower then for all other years and likely underestimates the actual amount of fishing effort for the 2003 fishery.

Yearly fishing intensity shows that the highest fishing intensity occurred in 2002 and 2004 (Fig. 4). Fishing intensity over all of SFA 29, and within subareas, shows a patchy distribution and the location of these patches are relatively consistent between years (Fig. 5). Subareas A and E experience the least fishing intensity while subareas C and D experience more consistent and intense fishing. The fishery did not begin in subarea D until 2004 when only the western portion was opened. While the whole of subarea D was opened in 2005, fishing mainly took place in the mid to northeastern portion of the subarea. Since then the fishery has occurred throughout subarea D. The proportion of area being fished in each subarea but subarea A has been consistent over the last three years (Fig. 6).

Cumulative fishing intensity is less in subareas A and E than all other areas (Fig. 7). The spatial distribution of fishing intensity within subareas is patchy and subareas C and D experience the highest cumulative fishing intensity.

Overlaying 'fishing' positions on the geophysical substrate map shows that fishing is mainly concentrated on the fairly broad and flat post-glacial deposit areas (Pg) in subareas C and D (Fig. 8). There appears to be less evidence for fishing being affiliated with bottom type in subareas A, B and E, the fishing positions in these areas do line up with topographical features such as troughs and valleys (not shown). These topographical features may contain

[1]Version 9.2. http://www.esri.com/

post-glacial deposits at a finer scale than represented on the map, however geophysical data were not available at that scale.

Modelling VMS data

A switching state-space model (SSSM) was implemented to objectively discriminate fishing positions from those associated with steaming or other non-fishing activities. This approach has been used successfully to identify area-restricted search behaviours associated with foraging activity from satellite telemetry tracking data of marine predators (Jonsen et al. 2005, Jonsen et al. 2007). The model assumes a correlated random walk on the differences in successive positions,

$$\mathbf{d}_t \sim N_2(\gamma_{b_t}\mathbf{T}(\theta_{b_t})\mathbf{d}_{t-1}, \mathbf{\Sigma}) \tag{1}$$

where $\mathbf{d}_{t-1}$ is the difference between the positions x_{t-1} and x_{t-2} and $\mathbf{d}_t$ is the difference between the positions $\mathbf{x}_t$ and $\mathbf{x}_{t-1}$. $\mathbf{T}(\theta)$ is a transition matrix that provides the rotation required to move from $\mathbf{d}_{t-1}$ to $\mathbf{d}_t$, where θ is the mean turning angle. The subscripts b_t denote the movement state (fishing or steaming) the vessel is in at time t. N_2 is a bivariate Gaussian distribution with covariance matrix $\mathbf{\Sigma}$.

The γ term was included to allow for variability in the autocorrelation of direction and speed; with $\gamma = 0$ resulting in a simple random walk and $0 < \gamma < 1$ yielding a random walk with correlation in both direction and move speed.

This model was fit to the VMS tracking data (GPS) via the observation equation,

$$\mathbf{y}_{t,i} = (1 - j_i)\mathbf{x}_{t-1} + j_i\mathbf{x}_t + \boldsymbol{\epsilon}_t \tag{2}$$

where $\mathbf{y}_{t,i}$ is the ith observed position during the regular time interval $t-1$ to t, j_i is the proportion of this time interval at which the ith observation is made ($0 < j_i < 1$), and $\boldsymbol{\epsilon}_t$ is a random variable representing the error in the GPS-derived positions. The j_i's are calculated from the data, assuming a one hour time step.

A Bayesian approach was used to fit the model, placing vague priors on model parameters, except for the movement parameters for the transitting mode; θ_1 and γ_1. For these parameters we used the following priors, $\theta_1 \sim \text{Beta}(20, 20)$ and $\gamma_1 \sim \text{Beta}(48, 16)$, reasoning that while transitting, turn angles should be closer to 0 and autocorrelation should be higher than when foraging. Normally-distributed errors were assumed in the observed GPS positions.

The model was fit with the freely available WinBUGS software (Lunn et al. 2000) which uses Markov Chain Monte Carlo (MCMC) methods to approximate the multi-dimensional integration required in Bayesian analyses. The model was fit to each dataset with a total of 30 000 MCMC samples, the first 10 000 were discarded as a burn-in and the remaining 20 000 samples were thinned out to 4 000 samples by retaining only every 5th sample to reduce autocorrelation.

Currently, the model is unable to discriminate properly between fishing and steaming states, this may be due to the low proportion of steaming locations in the vessel tracks. A hierarchical SSSM will be fit to multiple vessel tracks simultaneously, thereby borrowing

strength across datasets to estimate switches between fishing and steaming. This approach has worked successfully with other applications (Breed et al. in press).

Depletion estimates of exploitation

In last year's assessment (Smith et al. 2008b), exploitation rates in the 2007 fishery were estimated in subareas A to D using the depletion model described by Leslie and Davis (1939). Assuming a closed population, that is, no recruitment, natural mortality and minimal growth during the period of the fishery, then the population biomass at the beginning of the fishery (B_0) should decrease simply as a function of the catches (C_t) up to time t. That is,

$$B_t = B_0 - \sum_{i=0}^{t-1} C_i. \tag{3}$$

where $C_0 = 0$. Assuming that commercial catch rate K_t was observed at time t and that the catch rate was proportional to the biomass over time then,

$$\begin{aligned} K_t &= qB_t \\ &= q(B_0 - \sum_{i=0}^{t-1} C_i) \\ &= qB_0 - q\sum_{i=0}^{t-1} C_i. \end{aligned} \tag{4}$$

There are three main quantities that can be obtained from the model in equation 4. The slope is the catchability coefficient for the fishery, while dividing the intercept by the slope gives the population biomass B_0 at the beginning of the fishery. The exploitation rate of the fishery on the population at the end of the fishery (time I) can be estimated as,

$$\hat{E} = \frac{\sum_{i=1}^{I} C_i}{B_0} \tag{5}$$

In Smith et al. (2008b), the depletion model was cast as a Bayesian model with the likelihood for K_t in equation 4 set to be for a normal distribution with mean at time t equal to $B'_0 - q\sum_{i=0}^{t-1} C_i$ and variance σ^2. A normal non-informative prior was assigned to B'_0 (mean=0, variance=10^6) while a positive half normal distribution was used as the prior on q. A uniform (0,100) distribution was used as the prior on σ.

Catch rates within each of subareas A to D were calculated as the ratio of catch to effort by fleet and by day. Only commercial log data where catch, effort, date and location were provided, were used here. The number of records available by day and fleet were highly variable in addition to there being differing levels of variability of catch and effort for any one day and fleet. This variability was incorporated into the analysis by weighting the variance σ^2 in the model by the standard error associated with each daily catch rate estimate. That is, the variance associated with the model in equation 4 was expressed as $\mathbf{V}\sigma^2$, where $\mathbf{V}$ is a

diagonal matrix with element v_{ii} equal to the standard error for the catch rate for day i. The standard error was estimated using the jackknife estimate recommended by Smith (1980) for catch rate estimates.

Monte-Carlo markov chain simulations using the Gibbs sampler in WinBugs (Lunn et al. 2000) were used to find the estimates for this model. Two chains with separate starting values were used for each run with the first 10 000 replicates discarded as a burn-in and the second 10 000 replicates per chain kept to describe the posterior distributions of the parameters. The degree of convergence to the posterior distribution was evaluated using the Brooks-Gelman-Rubin method (Brooks and Gelman 1998).

The model was fit with both fleets combined and to each fleet separately. No trends or major differences were found that suggested that the model should be fit separately to each fleet. There was not always enough data to calculate depletion estimates for all areas in all years, only areas B and C have estimates for all years since 2002.

Data was limited in subarea A such that depletion estimates could only be calculated for 2004, 2006 and 2007 (Fig. 9). In the 2007 assessment it was suggested that a high rate of depletion may have been indicative of local conditions rather than the entire subarea (Smith et al. 2008b). Estimates for the total biomass at the beginning of the fishery were higher in 2004 and 2006, with medians of 166 t (95% credible bounds of 113 and 610) and 146 t (95% credible bounds of 42 and 3448) respectively. The exploitation rates were relatively high (median 0.45) in 2004 due to a large catch (81 t), low in 2006 (median 0.13) and high again in 2007 (median 0.67) which may be representative of a smaller area fished.

Subarea B is a large area where fishing generally takes place sequentially in localized pockets. Because of this, it is difficult to discern a depletion effect over the whole subarea. In most cases (except 2005) the model estimates gradual depletion and consequently results in high estimates of the initial biomass and low exploitation rates (Figs 10 and 11). It is likely that subarea B will need to be looked at a finer resolution in order to achieve accurate estimates of exploitation from the depletion model. An attempt was made to examine depletion in subarea B subdivided further first by bottom type and then by 4 polygons constructed to roughly divide different areas of concentrated fishing effort. Neither of these attempts were successful in achieving more accurate depletion estimates. In subarea B nearly all fishing effort occurs on the Ic1 substrate, so there was little difference in the depletions and the 4 polygons were still too large to capture depletion within the localized pockets.

The depletion model was most effective at achieving reasonable estimates of initial biomass and exploitation for subarea C (Figs. 12 and 13). A very high rate of depletion occurred in 2002 and resulted in estimates of initial biomass (552 t) and exploitation (0.79) that may be inaccurate or representative of a smaller area fished. In a wider context, it should be noted that catch rates in the beginning of 2003 are about the same as they were at the end of 2002, even though estimates of initial biomass in 2003 (409 t) were higher than the estimated biomass at the end of the fishery in 2002 ($551.7 - 440 = 112$ t).

Subarea D had very high rates of depletion in the first two years (2004 and 2005), resulting in low estimates of initial biomass and high estimates of exploitation (Fig. 14). These were likely representative of highly concentrated fishing effort over a short period of time. As with subarea C there were very high catch rates associated with the initial opening of the fishery which may have led to an overestimation of exploitation in 2004. In 2005 the depletion is

suspect since the TAC was achieved in only two days and therefore was based on only two data points.

Estimated initial biomass appears to scale with area fished as determined from the VMS records for all subareas, except for 2003 (Fig. 15). Recall that the area fished for 2003 was underestimated due to problems with the VMS records.

The lower estimated biomasses for D in 2004 and 2005 appear to reflect the smaller areas being fished in each of these two years. With the exception of subarea A, exploitation estimates from the depletion model appear to scale with catch especially in the last three years when the area fished has been consistent (Fig. 16).

Research survey

Annual surveys in SFA 29 have been conducted since 2001 when the current fishery started. The survey design for 2001 was a simple random design over the whole area. From 2002 to 2004, a stratified random design was used with strata defined by the management subareas A to E. Starting in 2005, strata have been defined by the bottom types as identified by geologists as part of the joint industry/government multibeam mapping project conducted in this area (DFO 2006). A new interpretation of the bottom types was made available in 2008 (Todd et al. 2009) and was used to design the survey for 2008.

Surveys over the whole area since 2001 have been conducted using a vessel from the Full Bay fleet for the survey (F/V Julie Ann Joan, 2001–2003, 2005–2007; F/V Branntelle 2004). Starting in 2005, approximately 30 additional survey stations in subareas C and D have been conducted by a vessel from the East of Baccaro fleet. Previous documents have commented on difficulties in the interpretation of comparative survey data from the East of Baccaro and Full Bay fleet vessels used to conduct the survey (e.g., Smith et al. 2007).

The annual survey in this area had been funded through a Joint Project Agreement between DFO and the scallop fishing industry since 2001. In 2007, the LaRocque court decision changed the funding basis for surveys like this one. Funds allocated by DFO in 2007, in response to the LaRocque decision were used to fund a basic survey of 90 stations over subareas A to D using the F/V Julie Ann Joan. The East of Baccaro fleet completely funded 30 survey stations using one of their own vessels in subareas C and D in 2007. Measurements of numbers, weight and shell height on this part of the survey were made by an industry technician who had been trained on the proper use of the scallop shell height measuring board. In 2008, LaRocque funds were obtained to fund both the Full Bay and the East of Baccaro vessels for the survey.

Abundance indices

Estimates of mean number per tow of commercial size scallops by subarea were calculated using the original subarea stratified design (2001 to 2004), the surficial sediment base map (2001 to 2007) and the new geophysical sediment based map (2001 to 2008, Figs 17 and 18). Estimates for the latter two designs were calculated using post-stratification formula for 2001 to 2004 and domain estimate formula for 2005 to 2007 (Särndal et al. 1992). Survey tows were assigned to their respective geophysical stratum by intersecting the position of the

tow with the corresponding substrate polygons using ArcGIS. Tows were created as polylines using the start and end locations of the tows. If a tow crossed > 1 substrate type, the tow was assigned the substrate type associated with the majority of that tow. The estimates for 2008 were calculated using the standard stratified random formula (Cochran 1977). There was no overall difference in trend for the estimates from the three different designs for either the Full Bay survey or the East of Baccaro survey. The geophysical-based estimates were virtually identical to those from the other designs in subarea B.

Smith et al. (2009b) evaluated the three different survey designs used here with respect to the precision of the associated estimates of mean number per tow for commercial size scallops from the 2001 to 2007 surveys. Overall, the geophysical based design resulted in more precise estimates (lower variance) of the mean when compared to a simple random sample design. The design efficiency for the 2008 of 16.17% was similar to that estimated for the 2007 survey using the geophysical design.

Shell height frequencies for subarea A (using the geophysical strata) show that small scallops were observed in 2006, 2007 and 2008 but if these scallops are of the same year-class then they are growing quite slowly (Fig. 19). The modal shell heights in 2007 and 2008 were 22.5 mm and 32.5 mm, respectively, both of which fall into the 0 to 1 years old based on ages determined from annual rings on shells suggesting that there were two year-classes here. No recruitment (90 to 100 mm) was found for 2009.

Similarly, the year-class identified at model shell height of 27.5 mm in subarea B in 2007 did not appear at the expected modal height of 60 to 70 mm (Fig. 20). A larger than average abundance of pre-recruits (modal height = 42.5 mm) was identified in the 2007 survey in subarea C but this did not translate into a similar higher abundance at 60 to 70 mm in the 2008 Full Bay survey (Fig. 21) but did seem to appear in the East of Baccaro survey (Fig. 22). In subarea D both the Full Bay survey (Fig. 23) and the East of Baccaro survey (Fig. 24) picked up the year-class in 2007 and again in 2008 but the year-class looks stronger in the 2008 east of Baccaro survey.

The Full Bay surveys for subarea A and B indicated that abundance has declined since the beginning of the fishery but has been more or less stable for the last three years (Fig. 25). Recruitment (90–100 mm) continued to be low. Both Full Bay and East of Baccaro surveys detected a sharp drop in abundance after the 2005 survey in subarea C with the former indicating stable abundance since then while the latter is showing an increase since 2006 (Fig. 26). Recruitment remains at lower than average levels. A similar drop in abundance after 2005 was also detected by both surveys in subarea D. Currently the Full Bay survey indicated increase from 2007 to 2008, although recruitment in 2007 was not above average, while the East of Baccaro survey suggested a continued decline from 2005.

Growth trends

In past research documents (e.g., Smith et al. 2008b) for SFA 29, growth models have been fit to either the meat weight or shell height and age data obtained from the annual survey to identify spatial patterns with respect to bottom type, subarea and depth. Spatial patterns are also routinely incorporated into meat weight/shell height relationships in the Bay of Fundy scallop assessments when estimating biomass from the surveys (Smith et al. 2008a).

Apart from identifying spatial patterns and estimating biomass, growth data are also important for determining reference points for exploitation rates (Smith et al. 2009a). In the Bay of Fundy the exploitation rate "replacement level", e'_t is defined as:

$$e'_t = \frac{\exp(-m_t)\left(\rho + \frac{\alpha}{\bar{w}_t}\right) - 1}{\exp(-m_t)\left(\rho + \frac{\alpha}{\bar{w}_t}\right)} \tag{6}$$

where m_t refers to the instantaneous natural mortality rate in year t, $\bar{w}_t$ is the average meat weight for the commercial size population in year t and ρ and α are obtained from a regression of the weights-at-age a on the weights-at-age $a-1$. This linear relationship is a consequence of using a von Bertalanfy growth curve for weight as a function of age (Quinn and Deriso 1999). However, it is difficult to incorporate spatial patterns when estimating ρ and α in this way.

The parameters ρ and α can also be directly obtained from the parameters of the von Bertalanfy growth curve for weight as:

$$\begin{aligned} \rho &= \exp(-K) \\ \alpha &= W_\infty(1-\rho) \end{aligned} \tag{7}$$

where W_∞ and K are parameters in the von Bertalanffy equation for growth of meat weight (W_t) with age (A_t). The parameter $W\infty$ corresponds to asymptotic (or maximum possible) size (e.g., meat weight in g) and K is often referred to as the Brody growth parameter and has units t^{-1}. In equation 7 the K parameter is actually for the growth rate of the shell height of the scallop defined as

$$H_t = H_\infty(1 - \exp(-K \times (A_t - T_0)))$$

where H_∞ is the asymptotic (or maximum) shell height, K is the growth rate and t_0 is an offset to adjust for the size at age 0. Shell heights are converted to meat weights using the relationship,

$$W_t = \exp(\beta_0) H_t^{\beta_1} \tag{8}$$

or more usually as the linear relationship

$$\log(W_t) = \beta_0 + \beta_1 \times \log(H_t) \tag{9}$$

Spatial patterns with respect to individual tows, survey subarea, geophysical bottom type or depth can be modelled via β_0 and β_1. These patterns can in turn be incorporated into the meat weight/shell age relationship as

$$W_t = W_\infty(1 - \exp(-K \times (A_t - T_0)))^{\beta_1} \tag{10}$$

where $W_\infty = \exp(\beta_0) L_\infty^{\beta_1}$ (page 140 in Quinn and Deriso 1999). Spatial patterns in the W_∞ and K terms can be incorporated in this model in addition to those already included in equation 9.

A two-step Bayesian model was developed to model log meat weight as a function of log shell height and then resulting parameter β_1 estimate was incorporated into modelling meat weight as a function of age. Spatial patterns were incorporated as random effects models with respect to survey tow, subarea or geophysical bottom type. Random effects were compared with the depths of the survey tows to identify possible relationships. Multiplicative errors (i.e., log normal) were assumed for the growth curves and non-informative priors were used for all random effects. All models were written, fit and tested using the WinBugs package (Lunn et al. 2000). The parameter estimate for β_1 was passed to the growth model using the `cut()` function in WinBugs to isolate the parameter estimates to their respective models. Models were screened using the Deviance Information Criteria (DIC, Spiegelhalter et al. 2002).

The first model in Table 4 represents meat weight fit directly to age with no connection to the meat weight/shell height relationship. Shell height was fit to Age in model 2 with W_∞ estimated by $W_\infty = \exp(\beta_0) L_\infty^{\beta_1}$. The remaining models pass the parameter estimate for β_1 through to the model in equation 10. The estimate for K from model 1 was less than half of the growth parameter from the shell height/age model in model 2, while estimates of K from models 3 to 12 were all very similar to the estimate in model 2.

Models 3 through 6 evaluate the level at which the random effects can be modelled for the meat weight/shell height relationship. Overall, the DIC criterion favours random effects at the individual tow level. Plotting random effects from the tow level model against depth (Fig. 27) suggests a weak relationship with depth; however, the DIC criterion for model 7 where depth is used in place of tow indicates that the tow level is the best model.

In model 8 random effects at the tow level are used for both the meat weight/shell height model and the meat weight/age model. The random effects for W_∞ exhibited a linear decline with depth (Fig. 27). Random effects at the subarea level and with respect to bottom type did not improve the model (models 9 and 10) over the tow level version. Depth effects were included into the W_∞ term in model 11 and this resulted in the best model overall in terms of DIC. Decreasing W_∞ with depth for scallops have been identified for other areas (Smith et al. 2001).

In previous years, evidence had been presented showing that W_∞ differed by bottom type as first defined by the geologists in NRCan (DFO 2006, Smith et al. 2008b). In this study the revised definitions from Todd et al. (2009) were used for the first time (Fig. 8) and the analysis did not identify bottom type in the best model for the spatial patterns in the growth data. Instead, depth which had not been looked at before for the data in SFA 29 was included in the best model. Depth ranges varied according to bottom type in the 2008 survey unlike the situation in the 2007 survey and as a result depth may be confounded with bottom type (Fig. 28). Further analysis will need to be done on all of the data collected to date to understand the impact of the interaction between depth and bottom type in the growth models.

Fishery bycatch

Lobster

Data sources for lobster bycatch come from both the scallop survey and observer data from the SFA 29 scallop fishery. The regular monitoring of the SFA 29 fishery by onboard observers is unique relative to other scallop fisheries and has been required since this fishery began in 2001.

The mean numbers of lobsters per tow in the 2008 scallop survey was again highest in subarea B at almost 4 lobsters per tow on average (Fig. 29, 30). Subarea B has had the highest catch rate of lobsters for most of the period from 2001–2008. Subarea A had the next highest lobster catch rate (approximately 2.3 lobster/tow) followed by subarea C (1 or 2 lobsters per tow depending on survey), and ¬ (< 0.5 lobster/tow). The size of lobsters in the survey ranged from 30 mm carapace length (CL) to 230 mm CL but most lobsters were between 50 and 120 mm CL and there was a strong mode at approximately 75 mm CL (Fig. 31).

The level of observer coverage has been variable over the history of this fishery. The level of observer coverage can be characterized in terms of the observed number of tows, observed number of days and observed number of trips (Table 5). The number of observed tows in 2008 was much higher than 2007 and in the mid to low range of the observer coverage from 2001–2006.

As in the scallop survey, most lobsters caught during observed fishing trips were in subarea B (Fig. 32) similar to previous years. The number of lobsters per ton of scallop meats was higher for the Full Bay fleet overall (Table 6). In terms of the open and closed portions of subarea B, the rate of lobster capture per ton of scallop meats was higher inside the closed area for the Full Bay fleet, and higher in the open portion for the East of Baccaro fleet.

Observer data on the number and condition of lobsters by subarea, are shown in Table 7 for the Full Bay fleet. Of the 1399 lobsters caught as a bycatch, 881 were uninjured, 397 were injured, 111 were dead and the condition was not recorded for 10. The same data are shown for the East of Baccaro fleet in Table 8. Of the 74 lobsters caught as a bycatch for this fleet, 55 were uninjured and 19 were dead or dying.

As in previous years' assessments, it is possible to estimate the total number of lobsters caught during scallop fishing by assuming the numbers of lobsters caught on the observed trips are representative. The number of lobster caught in each observed trip was converted to a number per tonne of observed scallop catch and then multiplied by the total scallop catch in the subarea of SFA 29 where the trips occurred. The estimated total number of lobsters caught by the Full Bay Fleet was 3888; the estimated number injured or dead was 287 (Table 9). These estimates are near the middle of the range of estimates for 2002–2007. For the East of Baccaro fleet, there was an estimated 647 lobsters caught, of which 43 were dead or dying. Summing the numbers from Tables 9 and 10, the estimated total number of lobsters caught as a bycatch during scallop fishing in SFA 29 in 2008 is 4535. Of these an estimated 330 were injured or dead. The total weight of the captured lobster was approximately 2.3 t (4535 lobsters, with an assumed average size of 85 mm CL and average weight of 0.5 kg). This weight is a small fraction ($< 0.1\%$) of the lobsters landed by the LFA 34 lobster fleet in the area corresponding to SFA 29.

As far as the direct effects of the scallop fishery on the lobster stock, the only information available is the catch during the scallop fishery and the scallop survey. There are no available data on how any bottom impacts might affect the lobster population. Some progress has been made on an analysis of underwater images to evaluate associations between lobster and habitat. This analysis indicates that there are significant associations between lobster and habitat with lobsters more evident on coarse bottoms than on gravel pavements typically associated with scallops (Tremblay et al. 2009).

Indirect information on the effect of the scallop fishery comes from trends in the lobster landings by the directed lobster fishery in LFA 34 (Table 11). Trends in lobster catches by the lobster fishery in the SFA 29 area as a whole are not indicative of an area that has been adversely affected by the scallop fishery since 2001. Lobster landings in SFA 29 in 2007/08 were higher relative to the previous year and relative to 5 years earlier. This is in contrast the area adjacent to SFA 29 and LFA 34 as a whole. These areas have experienced smaller increases (compared to 1 y earlier) or decreases (compared to 5 y earlier).

The lobster landings trends are consistent with the idea that the scallop fishery has not had a negative effect on the lobster fishery, but it is recognized that landings trends by themselves cannot confirm there has been no effect.

Direct injury and mortality of lobsters due to the scallop fishery is likely greater in localized areas of high lobster density such as portions of subarea B. Injury is also likely greater when lobsters are less mobile and less robust because they are soft-shelled. A review of the moult related data collected for the Lobster Quality and Moulting Project (`http://www.lobsterscience.ca/moult/`) was conducted for this stock assessment. Supplementary data are available from blood protein measurements on lobsters collected during the individual transferable quota (ITQ) groundfish trawl survey in early July and the SFA 29 scallop survey in October. This review will form part of a Canadian Technical Report of Fisheries and Aquatic Sciences (anticipated publication date of 2010). Preliminary results from this review confirms our understanding that the lobster moulting occurs from summer to fall but showed that there are considerable differences between years, and between areas. Moult timing is strongly controlled by temperature with the moult occurring earlier in the warmer, shallower areas of Lobster Bay than in the deeper water areas of SFA 29 (one sampling site was Jacquard's ridge, inside SFA 29 subarea B, Fig. 33). As temperatures are not constant year to year, the timing of the moult also varies. Between 2004 and 2008 moulting began in Lobster Bay between mid-June and mid-July and on Jacquard's Ridge between late July and early September. Peak molting (as indicated by 50% of lobster blood samples with a blood protein < 7 g/dL) occurred in Lobster Bay between mid-July and early August and on Jacquard's Ridge between mid-August and late September. Shell hardness information from Jacquard's Ridge and the SFA 29 survey indicate that recently moulted lobsters are present in October and that these may be more susceptible to capture by the scallop gear than the harder shelled animals that molted earlier.

Other species

Estimates of total catch of other invertebrates and fish species recorded by observers as being caught with the scallops were developed in a similar manner to estimates of total

lobster bycatch (see above; Table 12). Estimates for 2001 to 2007 and associated issues with these estimates were discussed in Smith et al. (2008b). Rock crabs, sculpins and Jonah crabs continue to be the dominant species in the bycatch in 2008. However, it has been previously noted that estimated catch weights of bycatch species are approximate as the observers generally record the lowest weights as one kilogram. It is likely that the catch weights of smaller animals (e.g., sculpins, hermit crabs, rock and Jonah crabs) were overestimated because of this practice.

Stock status and advice for 2009

The time series for the annual surveys, commercial catch rates and catch are still too short for the population dynamics to be adequately modelled in a manner similar to scallop populations in the Bay of Fundy. Advice was based on the interpretation of trends in the above time series.

The very patchy distribution of scallops in subarea A has resulted in a highly variable survey index and there did not appear to be much of a trend in this index in recent years. Commercial catch rates from both fleets have increased since 2006 over a period of declining catches. A 2009 catch in the range of 10 to 20 t is recommended.

The survey index for subarea B has been stable over the last three years while catches have declined from 116 t to 65 t. Commercial catch rates for the Full Bay fleet have declined by 19% during this same time period while the East of Baccaro fleet catch rates have remained stable. The depletion model indicated that relative exploitation declined from 2007 to 2008 from 0.17 to 0.08 with the decrease in catch from 80 t to 65 t. A catch level of between 60 to 80 t is recommended for 2009.

In subarea C the Full Bay survey index has been stable since 2006 while the East of Baccaro survey index has been increasing. Similarly, the Full Bay fleet commercial catch rates have also been stable over the last three years and the East of Baccaro fleet catch rates have increased from 2007 to 2008. During this same period catches have declined from 111 t to 54 t. Relative exploitation estimates have been stable for 2007–2008. Catches for 2009 are recommended to be in the range of 60 to 80 t.

The Full Bay survey index in subarea D suggested an increase from 2007 to 2008 while the East of Baccaro survey index indicated a continuous declining trend since 2005. Both commercial catch rate series have been decreasing since 2005 with a 31 to 34% reduction since 2006. While catches have declined from 156 t in 2006, the increase from 95 t in 2007 to 125 t in 2008 was estimated to have increased relative exploitation from 0.12 to 0.25. With three out of four indices showing declines at current catch levels, it is recommended that the 2009 catch be set to less than or equal to last year's TAC of 85 t.

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Table 1. Scallop landings and TACs (meats, t) for Scallop Fishing Area 29. Landings by subarea in 2001 determined from log records. TAC for subareas A, B and E were combined in 2004. TAC for subarea A and E combined in 2006.

		Full Bay		East of Baccaro		Total	
Year	Subarea	TAC (t)	Landings (t)	TAC (t)	Landings (t)	TAC (t)	Landings (t)
2001	A		(2)				
	B		(71)				
	C		(309)				
	U		(18)				
	Total	400	400			400	400
2002	A	75	1	25	4	100	5
	B	150	193	50	75	200	268
	C	375	334	125	106	500	440
	Total	600	528	200	185	800	713
2003	A						
	B	150	114	51	38	201	152
	C	188	33	63	32	251	65
	E		2		2		4
	Total	338	149	114	72	452	221
2004	A	150.0	70.2	50.0	9.9	200	80.1
	B		33.1		46.8		79.9
	E		0.2		3.4		3.6
	C	187.5	123.8	62.5	35.2	250	159.0
	D	112.5	148.6	37.5	40.0	150	188.6
	Total	450.0	375.9	150.0	135.3	600	511.2
2005	A	45.0	2.5	15.0	2.2	60	4.7
	B	30.0	22.7	10.0	26.3	40	48.9
	C	75.0	91.9	25.0	23.4	100	115.3
	D	41.25	63.2	13.75	10.7	55	73.9
	E		8.8		1.7		10.5
	Total	191.25	189.1	63.1	64.3	255	253.3
2006	A	18.75	20.4	6.25	1.1	25	21.5
	E		0.8		1.0		1.8
	B	93.75	87.8	31.25	27.8	125	115.6
	C	75.00	85.7	25.00	25.6	100	111.3
	D	112.50	113.0	37.50	42.9	150	155.9
	Total	300	307.7	100	98.4	400	406.1
2007	A	18.75	10.49	6.25	0.99	25.00	11.48
	E		0.24				0.24
	B	75.00	55.56	25.0	24.32	100.00	79.88
	C	37.50	47.86	12.5	11.03	50.00	58.89
	D	56.25	69.00	18.75	26.35	75.00	95.35
	Total	187.50	183.15	62.50	62.69	250.00	245.94
2008	A	7.50	3.05	2.50		10.00	3.05
	E		0.65		0.44		1.09
	B	82.50	44.65	27.50	20.75	110.00	65.40
	C	33.75	42.05	11.25	12.35	45.00	54.40
	D	63.75	99.37	21.25	26.02	85.00	125.39
	Total	187.50	189.77	62.5	59.56	250.00	249.33

Table 2. VMS 'fishing' records in SFA 29 during each fishing season.

Year	no. VMS Records
2002	21022
2003	640
2004	27302
2005	14031
2006	27363
2007	17744
2008	16164

Table 3. Comparison of Scallop Fishing Area 29 scallop survey design efficiency for three different stratification schemes. Efficiency was measured as the percent decrease in the stratified variance of the mean relative to variance of the mean from a simple random sample design (see Smith and Gavaris 1993). Subarea refers to stratification by management subarea, surficial strata as defined in the sediment map given in Smith et al. (2007). Prior to 2005, management subareas were used to design the survey while the surficial sediment map was used from 2005 to 2007. Survey catch data prior to 2008 was post-stratified using domain estimators (Särndal et al. 1992). The 2008 survey was designed using the Geophysical map (see text and Fig. 2).

	Stratified Design		
		Geological strata	
Year	Subarea	Surficial	Geophysical
2001	11.34	46.80	46.39
2002	5.57	28.15	19.16
2003	17.50	9.85	−8.04
2004	−2.67	11.67	21.95
2005		20.06	22.35
2006		−8.42	25.11
2007		−3.96	13.28
2008			16.72

Table 4. Results from analysis of growth data. Entries for the Groups columns correspond to no grouping factor (Null), individual tows (Tows), subarea (subarea), geophysical bottom type (Geophys.) and tow depth (Depths). For the Meat weight/Age model entries of the form Depth/Tows indicate that W_∞ was modelled in terms of depths while K was modelled in terms of tow location. Single entries for both models indicate that all of the parameters were modelled in terms of the factor listed. The column labelled $\widehat{W}_{1,\infty}$ refers to the regression coefficient for depth.

	Meat weight/shell height model				Meat weight/Age model					
Model	Groups	$\hat{\beta}_0$	$\hat{\beta}_1$	DIC	Groups	$\widehat{W}_{0,\infty}$	$\widehat{W}_{1,\infty}$	$\hat{K}$	$\hat{T}_0$	DIC
1	Null	2.85	2.72	−285.78	Null	33.93		0.17	0.77	5479.39
2	Null	2.85	2.72	−285.86	Null	27.87		0.36	−0.13	6352.96
3	Null	2.85	2.72	−285.71	Null	29.42		0.36	−0.04	5289.33
4	Tows	2.82	2.83	−784.86	Null	29.49		0.36	−0.09	5334.80
5	Subarea	2.83	2.80	−562.56	Null	29.93		0.36	−0.09	5299.19
6	Geophys.	2.84	2.75	−423.10	Null	30.10		0.35	−0.09	5323.69
7	Depth	2.82	2.83	−768.25	Null	36.27		0.30	−0.31	4862.25
	slope	−0.01	−0.002							
8	Tows	2.82	2.83	−785.49	Tows	35.59		0.31	−0.29	4798.92
9	Tows	2.82	2.83	−784.66	Subarea	35.16		0.27	−0.37	5095.07
10	Tows	2.82	2.83	−784.88	Geophys.	29.12		0.37	−0.12	5223.18
11	Tows	2.82	2.83	−785.48	Depth/Tows	37.54	−0.35	0.29	−0.36	4761.32
12	Tows	2.82	2.83	−784.84	Depths/Subarea	39.08	−0.32	0.26	−0.48	4892.79
13	Tows	2.82	2.83	−785.29	Depth/Geophys.	37.33	−0.23	0.28	−0.37	4865.28
14	Tows	2.82	2.83	−784.82	Depth/Null	38.65	−0.28	0.25	−0.45	4901.45

Table 5. Amount of observer coverage by fleet and year in the Scallop Fishing Area 29 scallop fishery. EoB = East of Baccaro fleet.

	Tows observed		Days observed		Trips observed	
Year	EoB	Full Bay	EoB	Full Bay	EoB	Full Bay
2001		2014		97		45
2002	1933	2521	78	98	33	36
2003	820	1524	33	56	10	18
2004	1305	3135	42	103	13	31
2005	502	1414	15	50	5	14
2006	895	2157	30	67	7	17
2007	3	947	1	28	1	7
2008	548	1969	17	67	4	19

Table 6. Lobster catch rate (numbers per tonne of scallop meats) inside and outside of the closed areas in subarea B from observer data for the 2008 SFA 29 scallop fishery.

	Full Bay		East of Baccaro	
Observed	Open	Closed	Open	Closed
no. of lobsters	827	526	60	10
scallop meats (t)	12.3	5.0	1.4	1.0
no. Lobster/meat (t)	67	104	43	10

Table 7. Numbers of lobsters and condition notes recorded by observers during 1,969 tows aboard vessels of the Full Bay Scallop Fleet during the 2008 scallop fishery in SFA 29. Note that condition was not recorded for all lobsters caught.

		Released Alive			
Subarea	N/A	No injury	Injured	Dead/Dying	Total
A	0	5	0	1	6
B	10	849	386	108	1353
C	0	1	0	0	1
D	0	1	1	0	2
E	0	25	10	2	37
Total	10	881	397	111	1399

Table 8. Numbers of lobsters and condition notes recorded by observers during 538 tows aboard vessels of the East of Baccaro Scallop Fleet during the 2008 scallop fishery in SFA 29. Note that condition was not recorded for all lobsters caught.

		Released Alive			
Subarea	N/A	No injury	Injured	Dead/Dying	Total
A	0	0	0	0	0
B	0	51	14	5	70
C	0	4	0	0	4
D	0	0	0	0	0
E	0	0	0	0	0
Total	0	55	14	5	74

Table 9. Estimated total numbers of lobsters caught in the scallop fishery by Full Bay Scallop fleet for 2001–2008 based upon observer data. DI (%) refers to the percentage of dead or injured lobsters.

		Observer data			Fishery	Estimated	
Year	Area	No. Lobsters	DI (%)	Meats (t)	Meats (t)	No. Lobsters	DI
2001	A	35		0.4	2	183	
	B	706		23.2	71	2158	
	C	102		72.2	309	436	
	Unknown				18		
	Total	843		95.8	400	2777	
2002	A	0	0	0.0	1	0	
	B	815	38	33.0	193	4773	1814
	C	90	39	43.6	334	690	269
	E	0	0	0.0		0	
	Total	905		76.6	528	5463	2083
2003	A	0	0	0.0	0	0	
	B	1297	37	31.4	114	4713	1743
	C	38	39	9.1	33	138	54
	E	78	33	NA	2	NA	
	Total	1413		80.5	149	4851	1797
2004	A	12	30	11.4	70.2	74	22
	B	200	15	12.6	33.1	527	79
	C	87	14	22.3	123.8	483	68
	D	3	33	9.6	148.6	46	15
	E	20	20	0.2	0.2	26	5
	Total	322		56.1	375.9	1156	189
2005	A	0	0	0	2.5	0	
	B	151	24	3.3	22.7	1047	251
	C	50	17	12.3	91.9	375	64
	D	0	0	5.4	63.2	0	
	E	107	19	3.1	8.8	308	59
	Total	308		24.1	189.1	1730	374
2006	A	17	18	1.1	20.4	309	56
	B	640	37	14.7	88.5	3861	1429
	C	30	43	6.6	86	393	169
	D	9	11	13.1	113.1	78	9
	E	0	0	0	0.01	0	
	Total	696		35.4	308.0	4641	1662
2007	A	7	0	1.28	10.49	57	0
	B	155	24	2.68	55.56	3213	771
	C	24	20	2.3	47.86	499	100
	D	8	38	7.71	69.00	72	27
	E				0.24		
	Total	194		14.0	183.15	3842	898
2008	A	6	17	0.8	3.0	24	4
	B	1353	8	17.4	44.6	3478	278
	C	1	0	0.2	42.5	266	0
	D	2	0	8.8	102.5	23	0
	E	37	5	0.2	0.6	97	5
	Total	1399	8	27.3	193.3	3888	287

Table 10. Estimated total numbers of lobsters caught in the scallop fishery by East of Baccaro fleet for 2001–2006, 2008 (no data in 2007) based upon observer data. NA = observer did not record scallop catch. DI (%) refers to the percentage of dead or injured lobsters. Entries for meat weights from observer data for 2003 and 2005 corrected for errors contained in Table 11 in Smith et al. (2007).

		Observer data			Fishery	Estimated	
Year	Area	No. Lobsters	DI (%)	Meats (t)	Meats (t)	No. Lobsters	DI
2002	A	8	25	0.1	4	460	115
	B	110	15	6.5	75	1268	190
	C	39	26	27.9	106	148	38
	E	0	0	0		0	
	Total	157		34.5	185	1876	343
2003	A	0	0	0	0	0	
	B	72	29	4.7	38	579	168
	C	184	13	6.2	32	953	124
	E	61	0	NA	2	NA	
	Total	317		10.9	72	1532	292
2004	A	3	0	1	9.9	29	0
	B	421	16	13.8	46.8	1426	228
	C	3	0	3	35.2	35	35
	D	0	0	1.4	40	0	
	E	0	0	0	3.4	0	
	Total	427		19.2	135.3	1490	263
2005	A	0	0	0	0	0	
	B	480	23	5.2	26.3	2426	558
	C	4	50	0.6	23.4	163	82
	D	0	0	0	0	0	
	E	25	12	0.5	1.7	81	10
	Total	509		6.3	51.4	2670	650
2006	A	0	0	0	8.8	0	
	B	794	17	11.1	27.9	2002	340
	C	46	37	2.5	25.3	464	172
	D	0	0	0.8	43.9	0	
	E	0	0	0	3.5	0	
	Total	840		14.3	109.4	2466	512
2008	A	0	0	0	0.0	0	0
	B	70	7	2.4	20.4	606	43
	C	4	0	1.2	12.3	42	0
	D	0	0	1.2	26.0	0	0
	E	0	0	0	0.4	0	0
	Total	74	7	4.8	59.2	647	43

Table 11. Recent lobster landings (t) by the LFA 34 lobster fishing fleet. Shown are the landings by SFA subarea, for SFA 29 as a whole, for the area adjacent to SFA 29, and LFA 34 as a whole. 1 year change is 2007/08 relative to 2006/07; 5 year change is 2007/08 relative to 2002/03. 2007/08 landings are preliminary.

	Scallop Fishing Area 29						Adjacent to	
Year	A	B	C	D	E	Total	SFA 29	LFA 34
2000/01	352	1343	432	348	538	3013	4584	16503
2001/02	448	1566	565	294	631	3504	5284	19055
2002/03	323	1239	632	432	499	3125	4805	17607
2003/04	367	1131	649	387	484	3018	4906	17801
2004/05	314	971	714	493	363	2855	4224	17237
2005/06	335	1120	937	596	479	3468	4545	16997
2006/07	362	1020	796	609	547	3335	4468	16577
2007/08	605	1265	840	581	658	3949	4754	17137
				% Change				
1 Year	67.1	24.0	5.5	−4.6	20.3	18.4	6.4	3.4
5 Year	87.3	2.1	32.9	34.5	31.9	26.4	−1.1	-2.7

Table 12. Estimated catches (t) of bycatch species in the SFA 29 scallop fishery based upon the observer database. Species arranged in descending order according to mean catch over 2001–2007.

	Catch (t)							
Species	2001	2002	2003	2004	2005	2006	2007	2008
jonah crab	3.51	8.6	18.1	10.23	9.25	16.79	24.47	3.80
Atlantic rock crab	4.9	21.37	5.58	6.87	3.21	38.27	1.58	7.55
hermit crabs	1.13	7.19	1.24	3.12	1.67	3.3	18.13	3.97
longhorn sculpin	1.12	6.42	2.24	4.84	3.51	6.15	2.92	7.05
thorny skate	1.55	0.31	1.11	2.02	0.69	1.03	8.34	0.69
monkfish	1.01	8.88	0.72	1.75	0.69	1.11	0.64	0.90
toad crab,unident.		7.62		0.06	0.01	0.21		
skates (ns)	0.88	2.21	0.76	1.58	0.49	0.02		0.22
northern stone crab							5.9	
winter skate	0.48	1.49	0.62		1.5	0.62	0.04	1.11
sculpin (ns)	1.36	11.32	1.38	1.64	2	0.85	3.09	
cancer crab (ns)							3.93	1.15
winter flounder	0.19	0.67	0.14	1.07	0.28	0.42	0.25	0.86
smooth skate	0.1	1.8	0.01	0.39	0.59	0.05		0.02
little skate		0.51			0.11	1.64	0.04	1.52
round skate			0.08		0.02	0.61		
yellowtail flounder	0.01	0.14	0.01	0.16	0.03	0.12	0.22	0.05
witch flounder	0.02	0.01	0.04	0.22	0.02	0.14	0.02	
cod	0.03	0.04		0.01	0.02	0.07	0.09	
american plaice	0.05	0.03	0.01			0.04	0.06	
striped Atlantic wolffish	0.01			0.08	0.05	0.03		0.00
lumpfish	0.1				0.01	0.02		0.00
barndoor skate		0.07						
ocean pout(common)		0.01	0.01	0.02		0.03		
redfish				0.01		0.03		
haddock		0.04						
spider crab (ns)	0.02							
halibut			0.01	0.01				0.01
flounder unidentified				0.02				
grubby or little sculpin						0.02		
summer flounder	0.01							
shorthorn sculpin						0.01		
mailed sculpin						0.01		
white hake		0.01						
pollock		0.01						

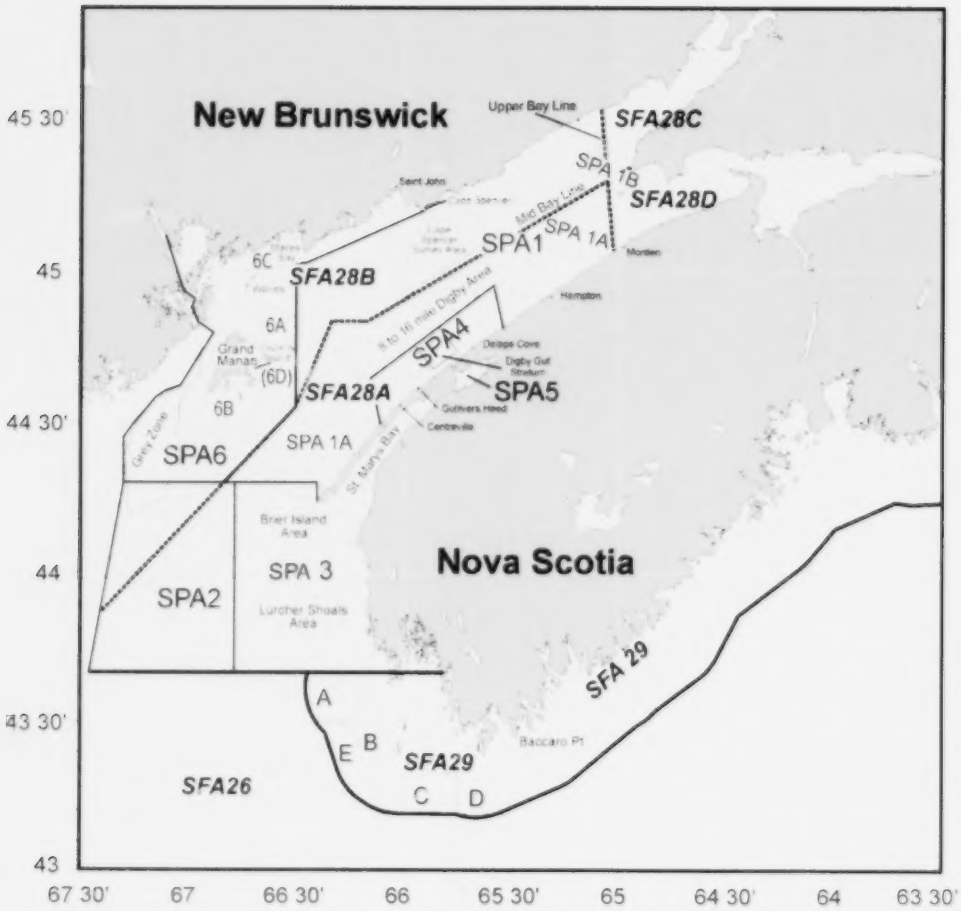


Fig. 1. Map of Scallop Fishing Areas (SFA) and Scallop Production Areas (SPA).

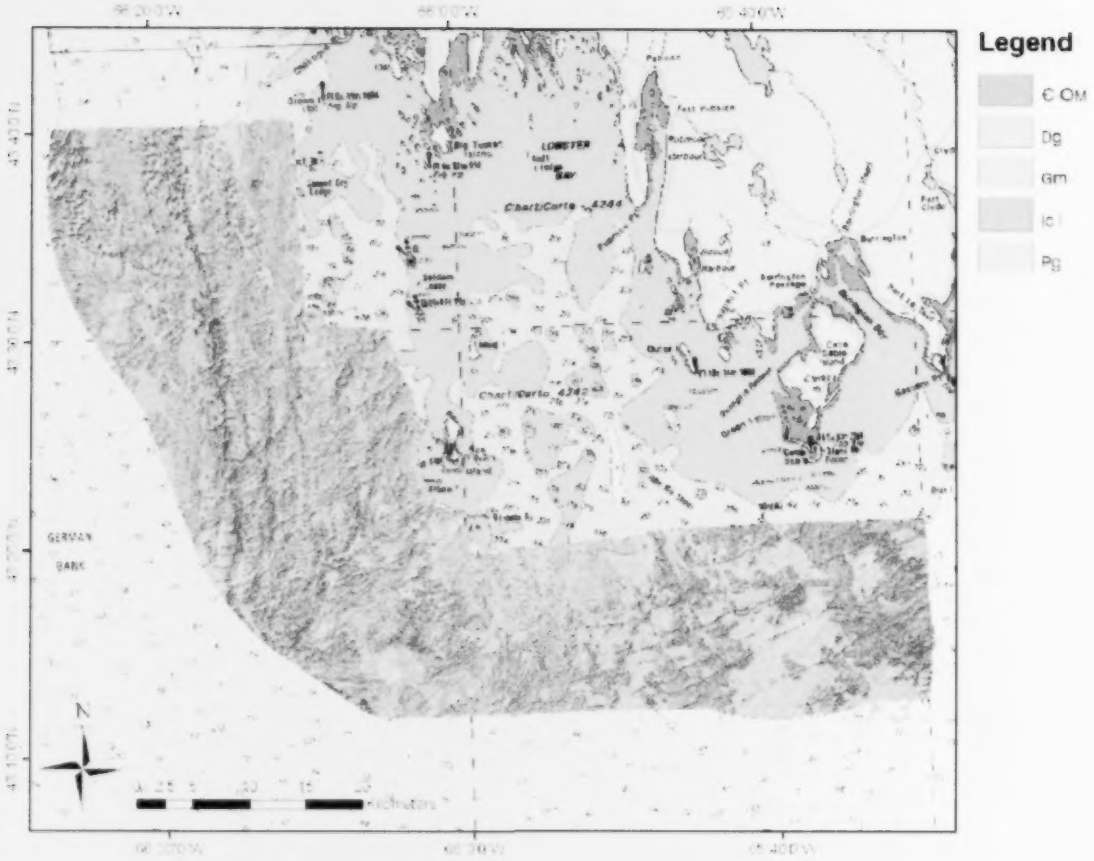
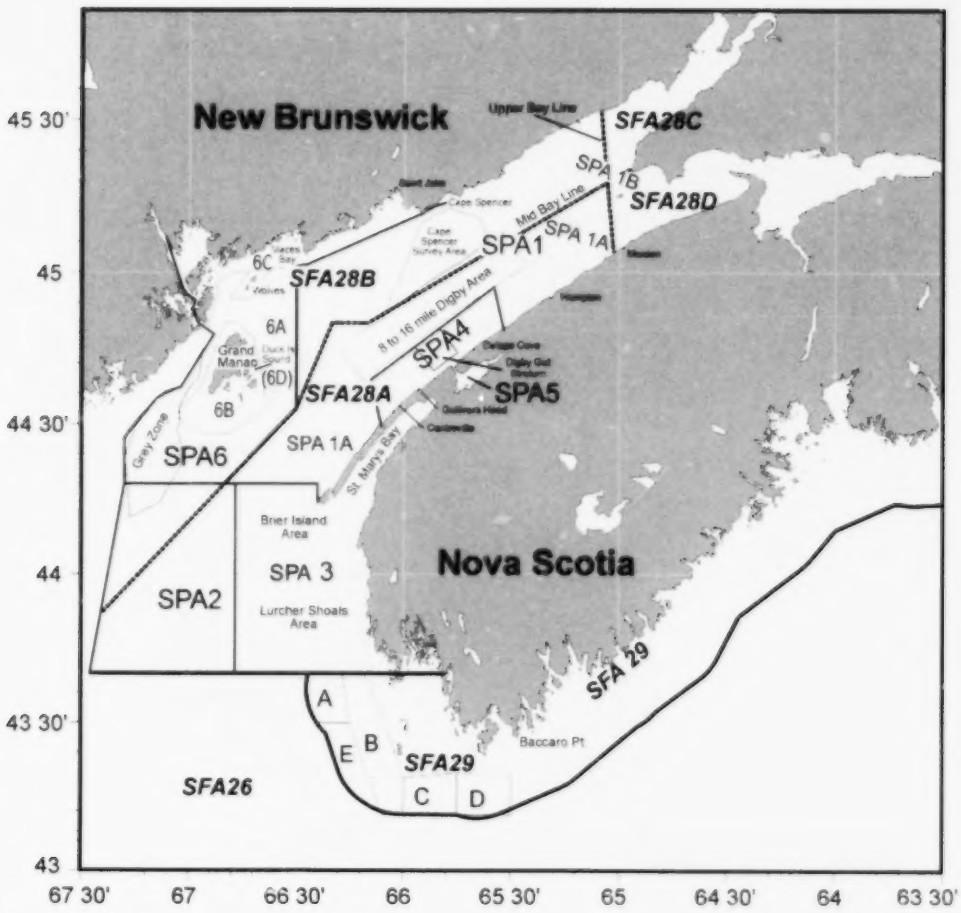


Fig. 2. Scallop Fishing Area (SFA) 29 study area with geophysical map. Bottom types defined as follows. €-Om = Metamorphic bedrock (granite), Dg = Igneous bedrock, Gm = Glaciomarine silt, Icl = Ice-contact sediment (till), Pg = Postglacial sand and gravel.



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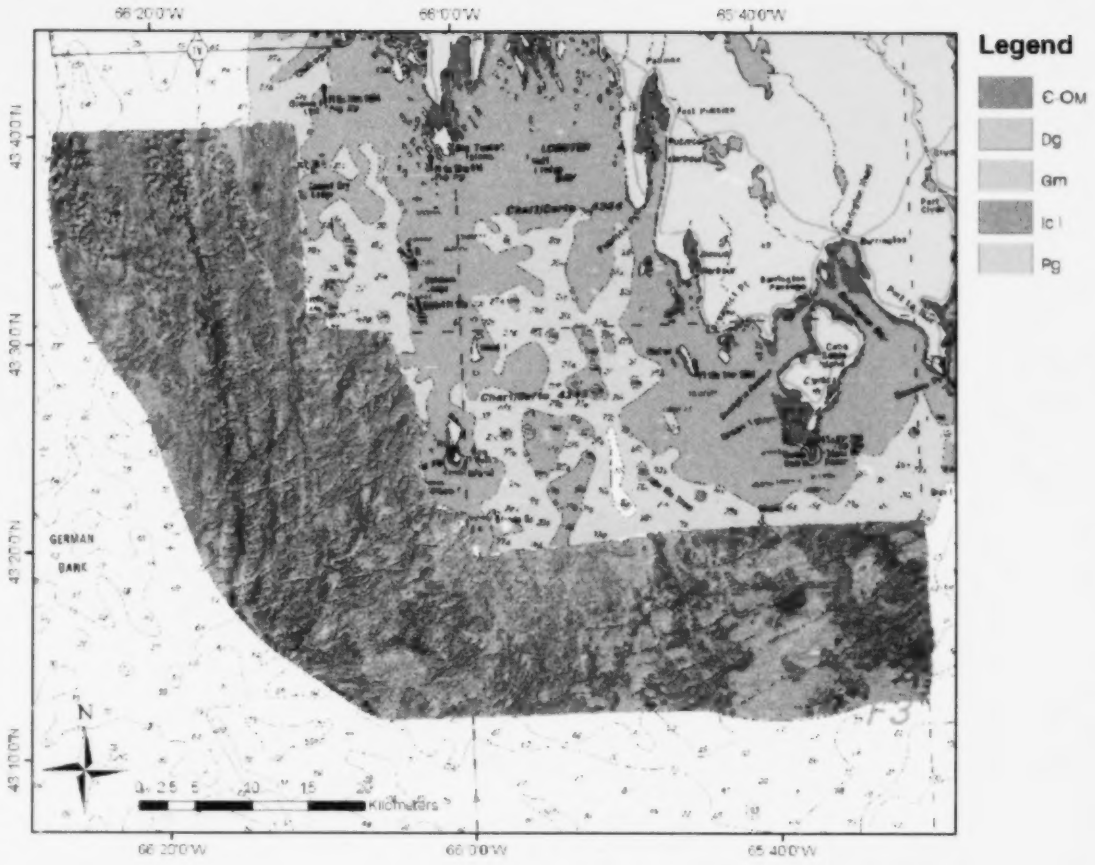

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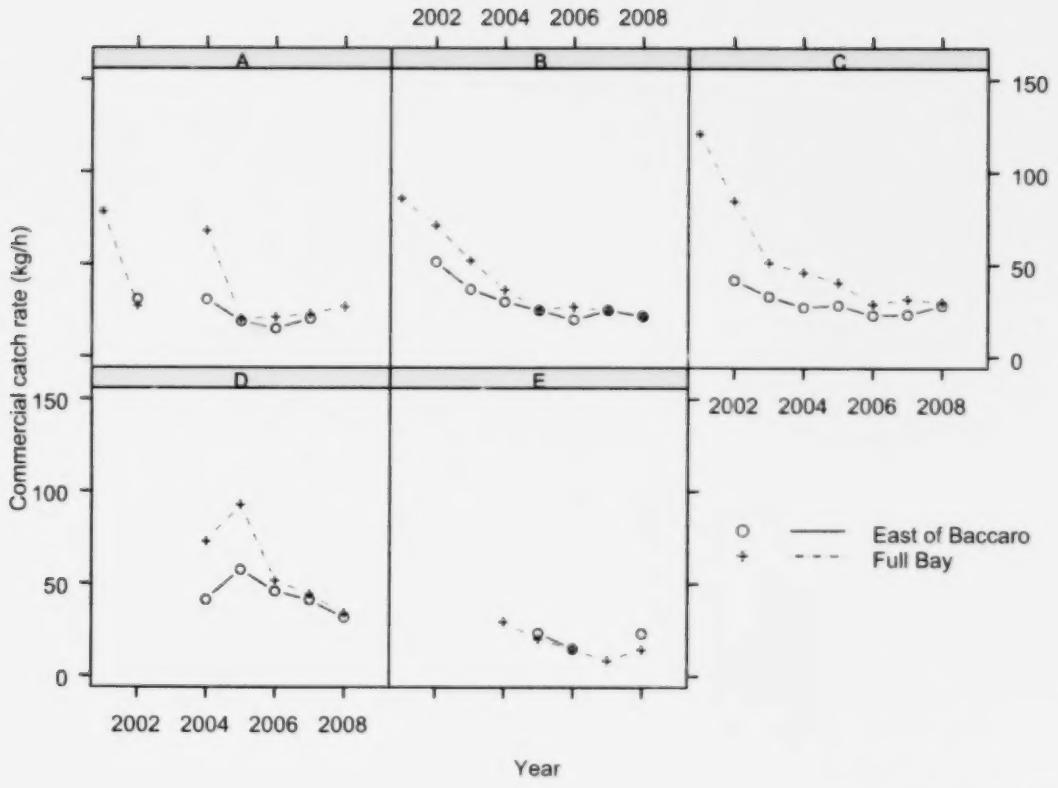


Fig. 3. Annual trends for average commercial catch rate (kg/h) for SFA 29 scallop fishery for each subarea by fleet.

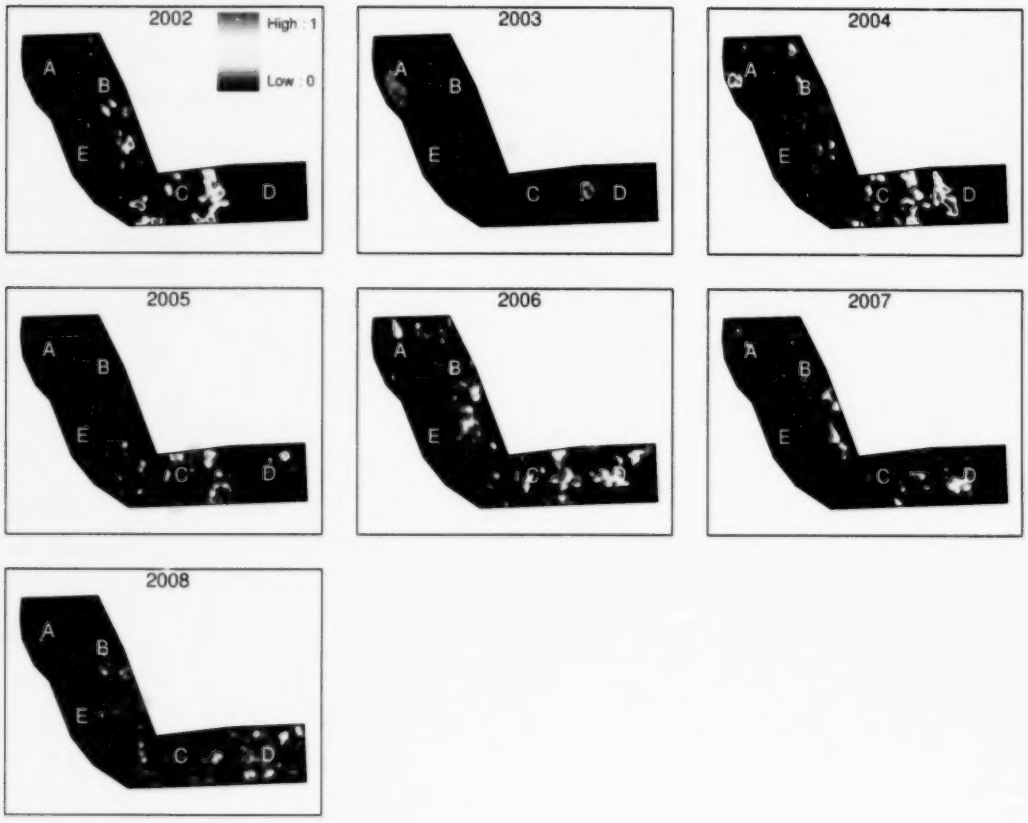
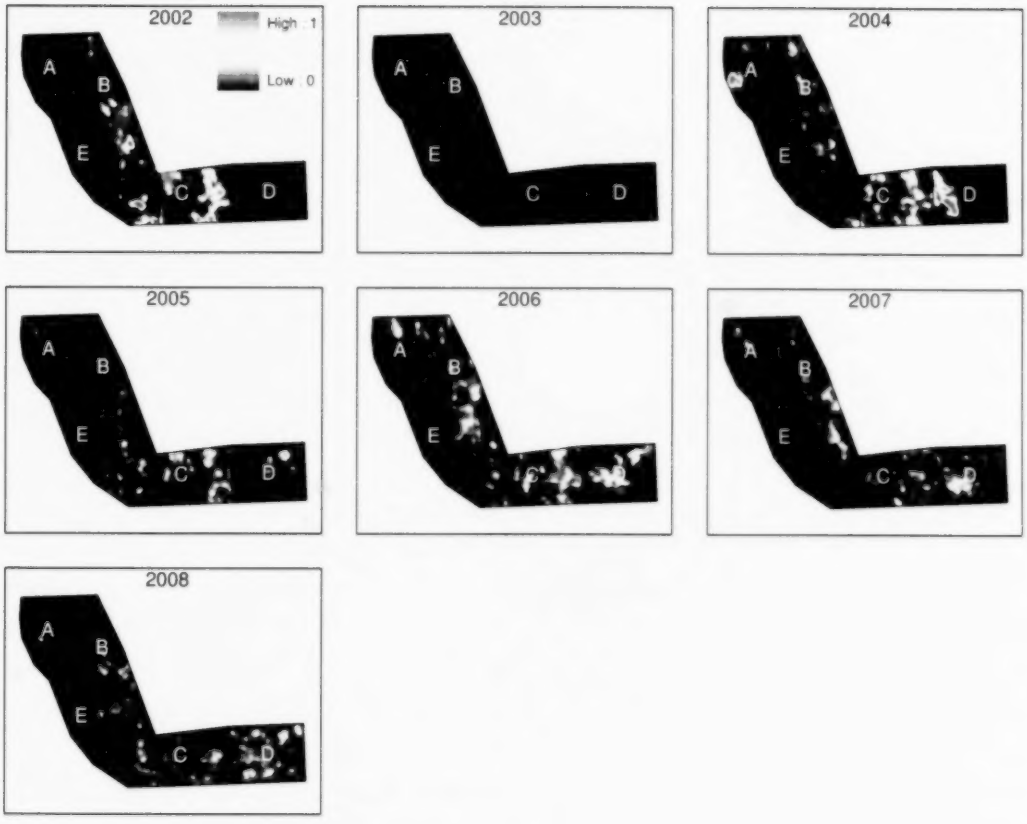


Fig. 4. Fishing intensity (no. pings/sq km) in SFA 29 by year based on VMS records filtered for speeds between 0 and 4 kt. Maximum intensity standardized to maximum over the time series.



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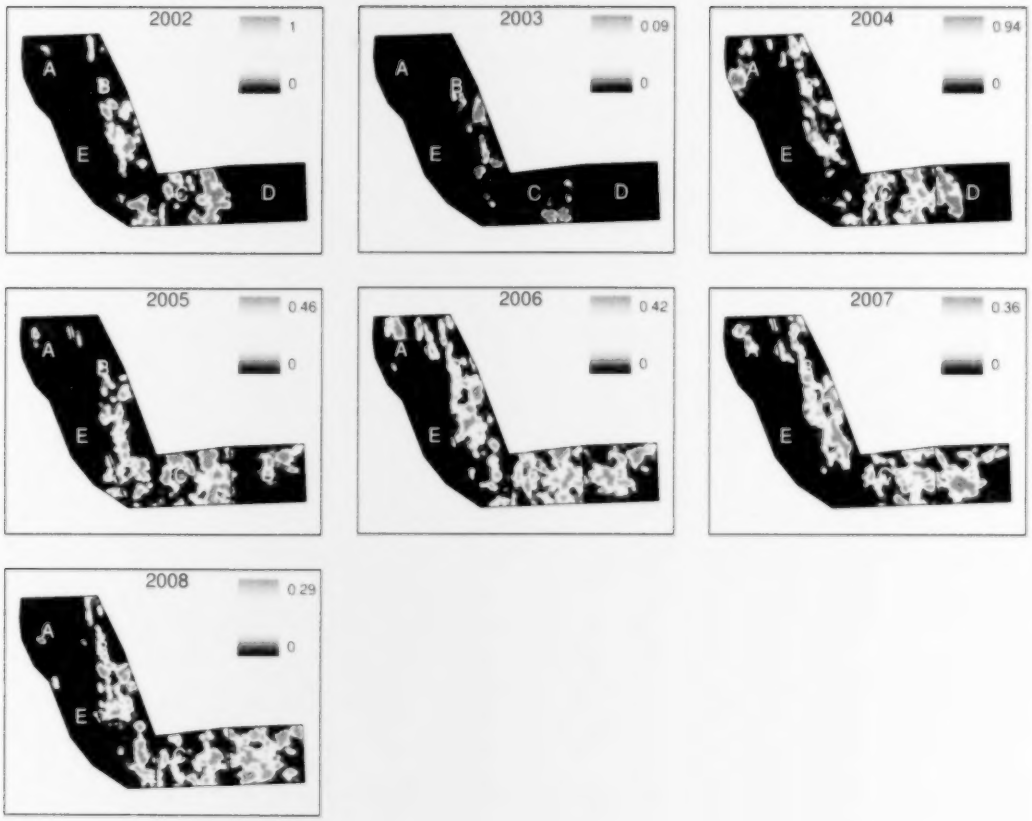
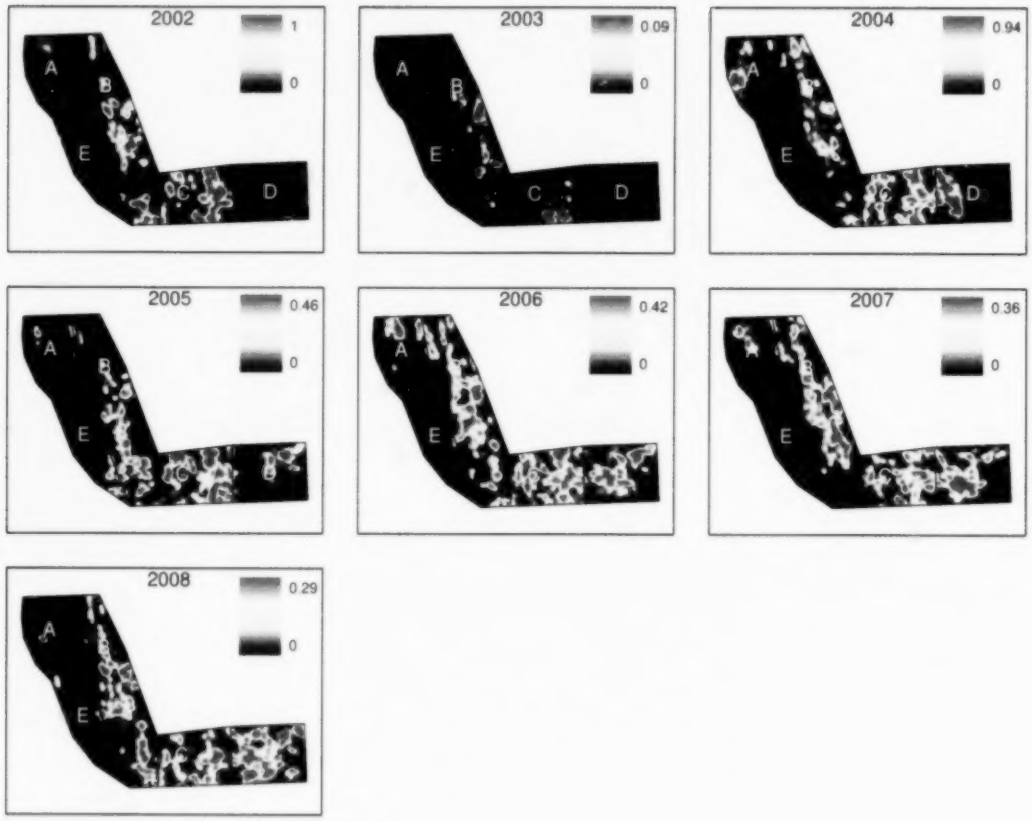


Fig. 5. Fishing intensity (no. pings/sq km) in SFA 29 by year based on VMS records filtered for speeds between 0 and 4 kt. Maximum intensity standardized to maximum for each year.



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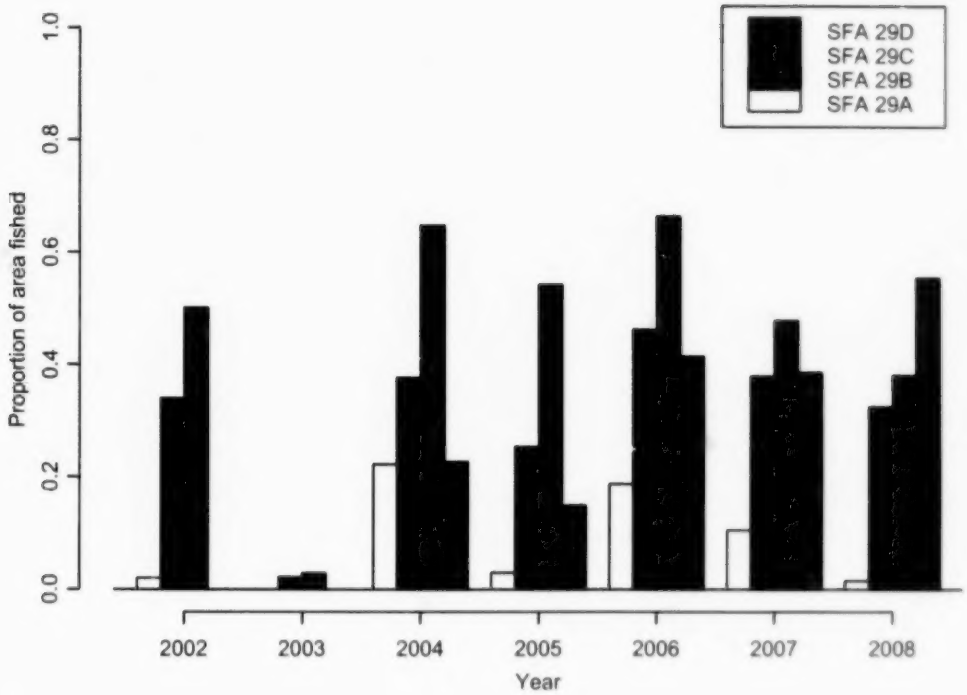


Fig. 6. The proportion of area being fished in SFA 29 was calculated as the summed area where the fishing intensity was > 0.01.

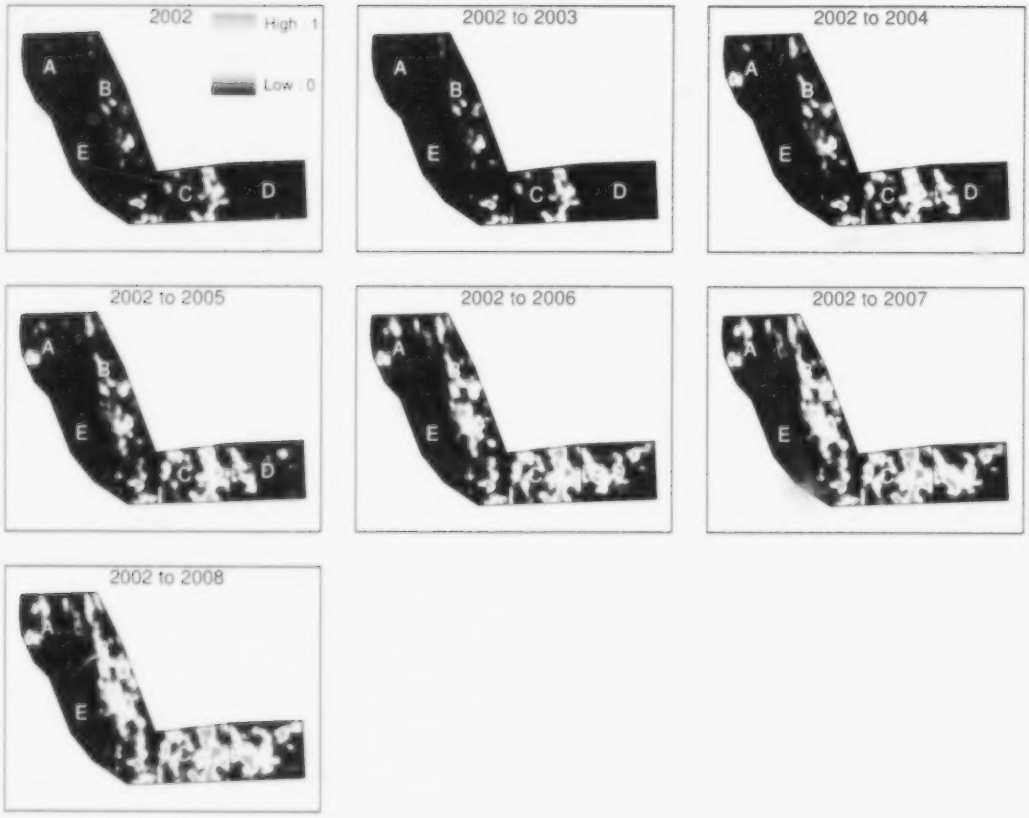


Fig. 7. Cumulative Fishing intensity (no. pings/sq km) in SFA 29 by year based on VMS records filtered for speeds between 0 and 4 kt. Maximum intensity standardized to maximum over the time series.

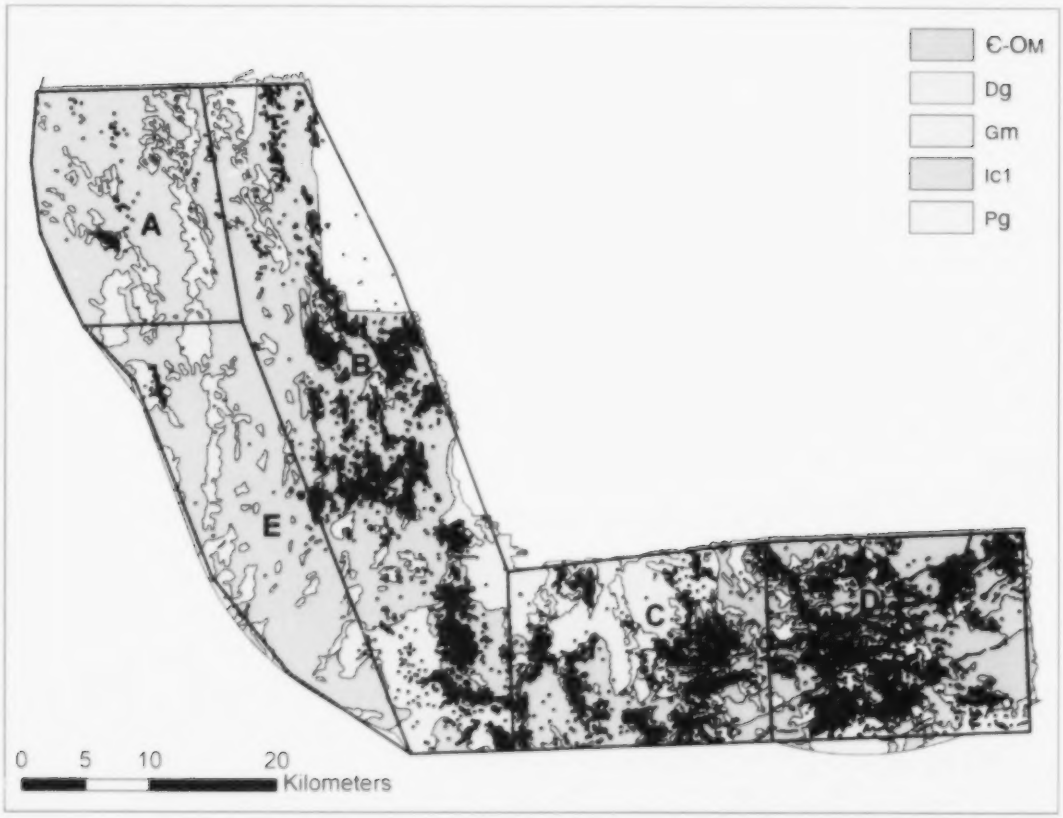
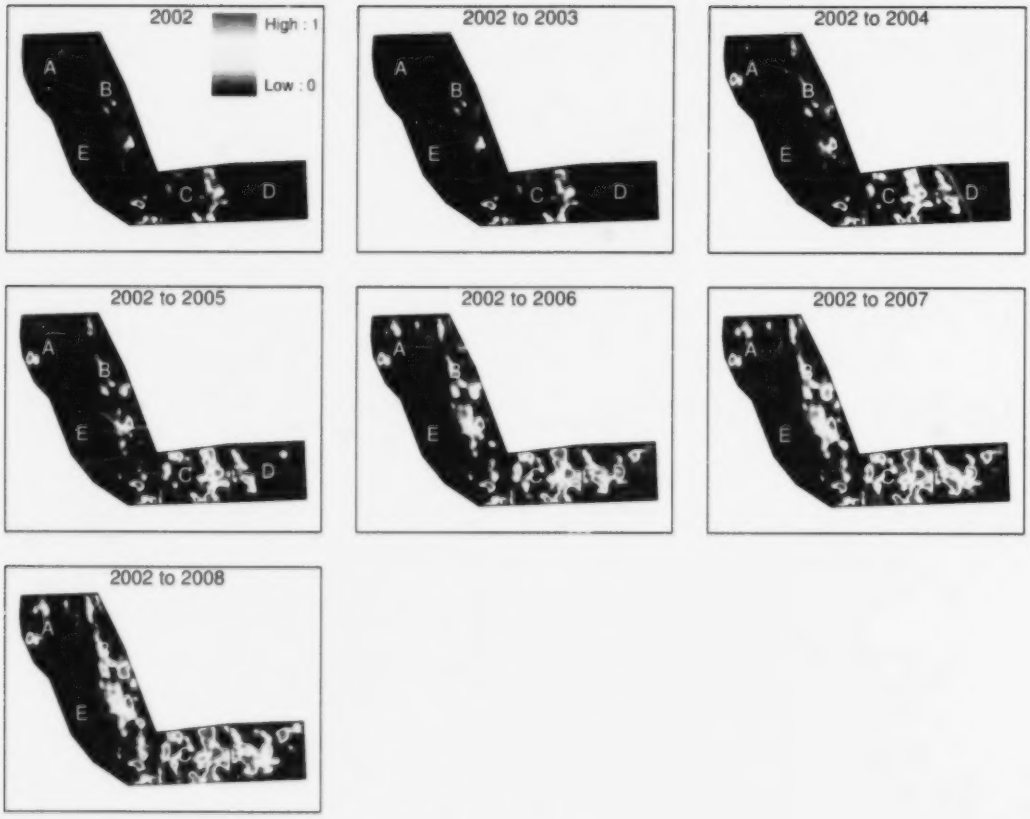


Fig. 8. Locations of fishing in SFA 29 mapped onto geophysical substrate map in 2008 based on VMS records filtered for speeds between 0 and 4 kt. Legend for geophysical substrate types (see text).



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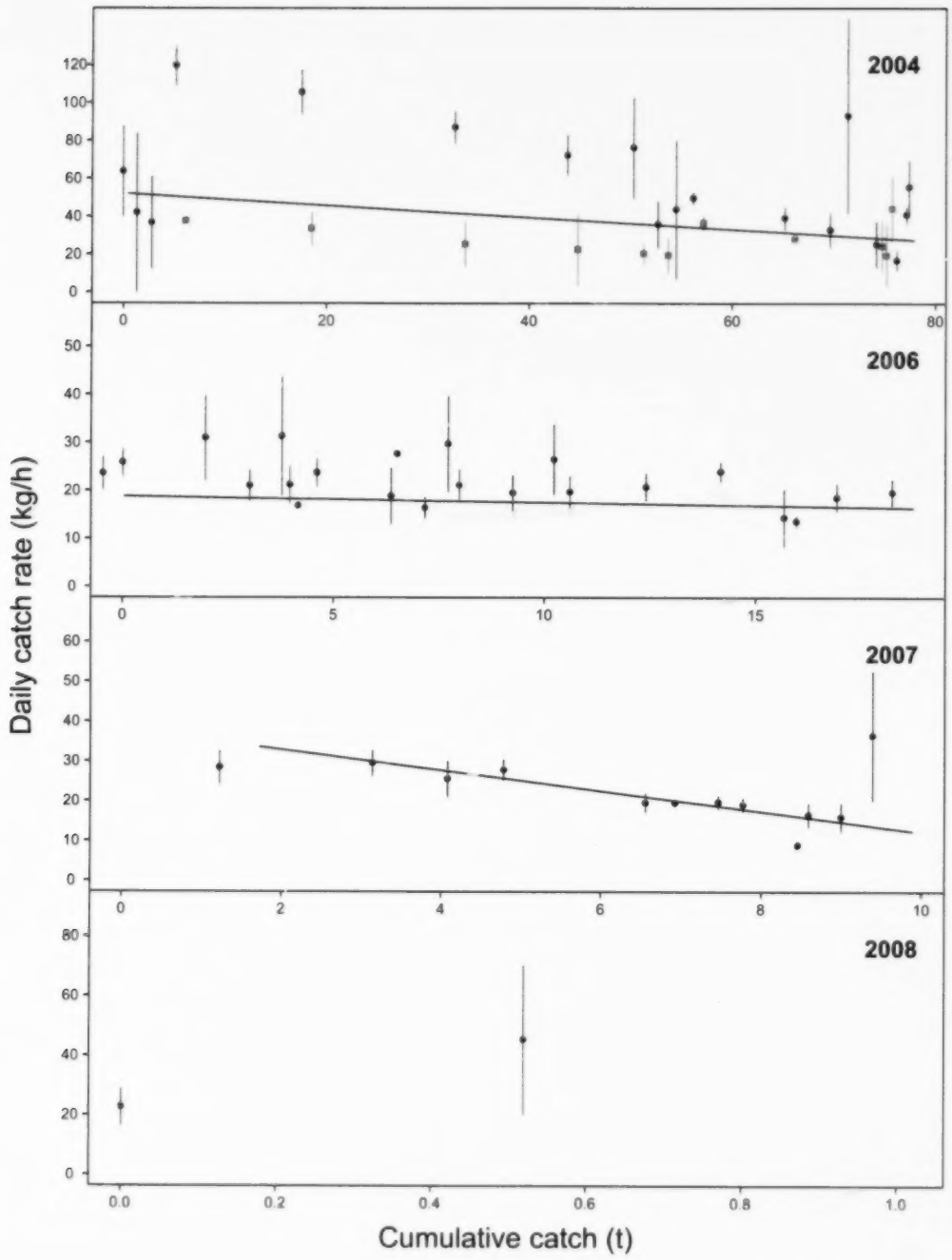

Fig. 9. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea A Scallop fishing area 29 for 2004, 2006 to 2008. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

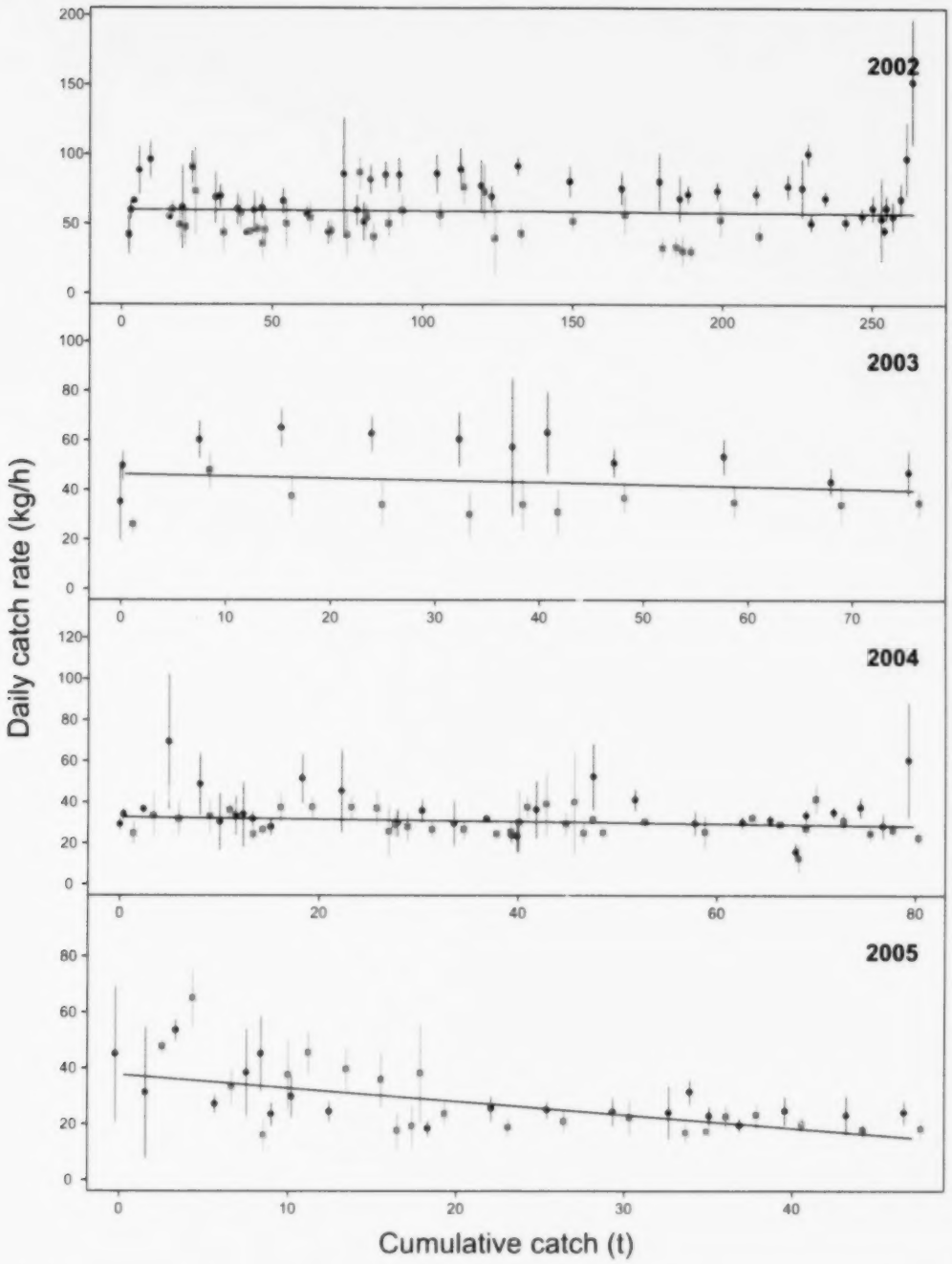

Fig. 10. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea B Scallop fishing area 29 for 2002 to 2005. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

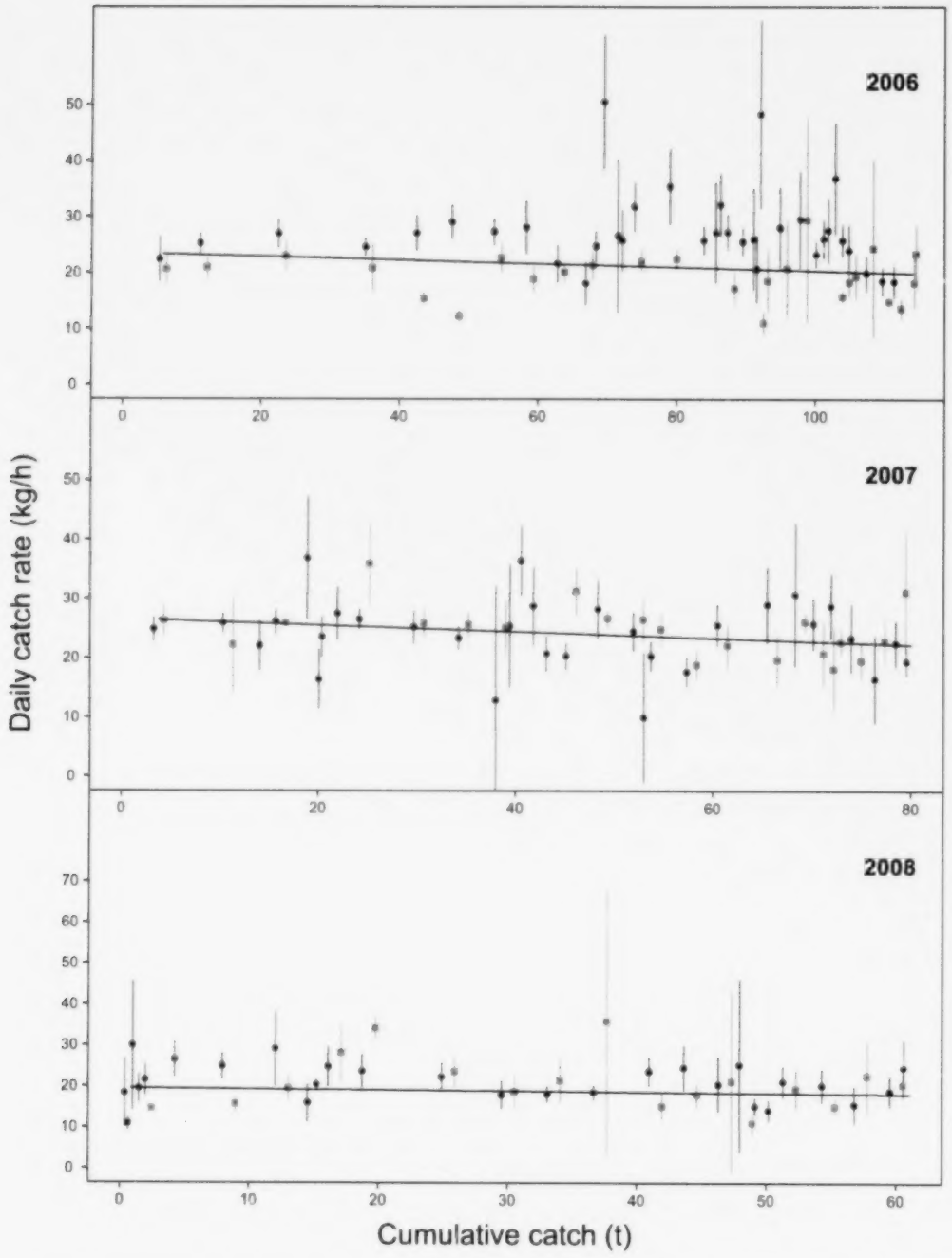

Fig. 11. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea B Scallop fishing area 29 for 2006 to 2008. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

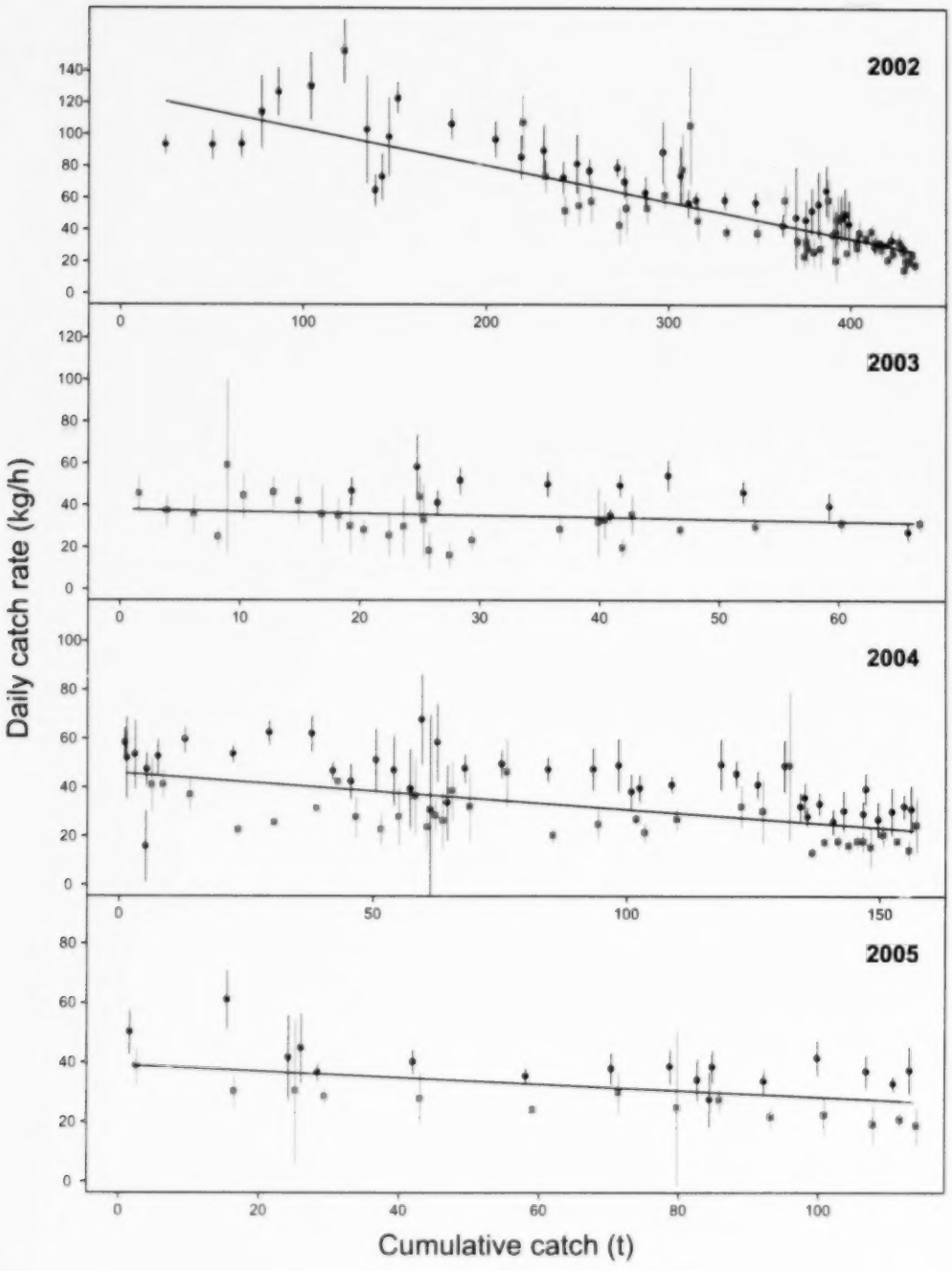

Fig. 12. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea C Scallop fishing area 29 for 2002 to 2005. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

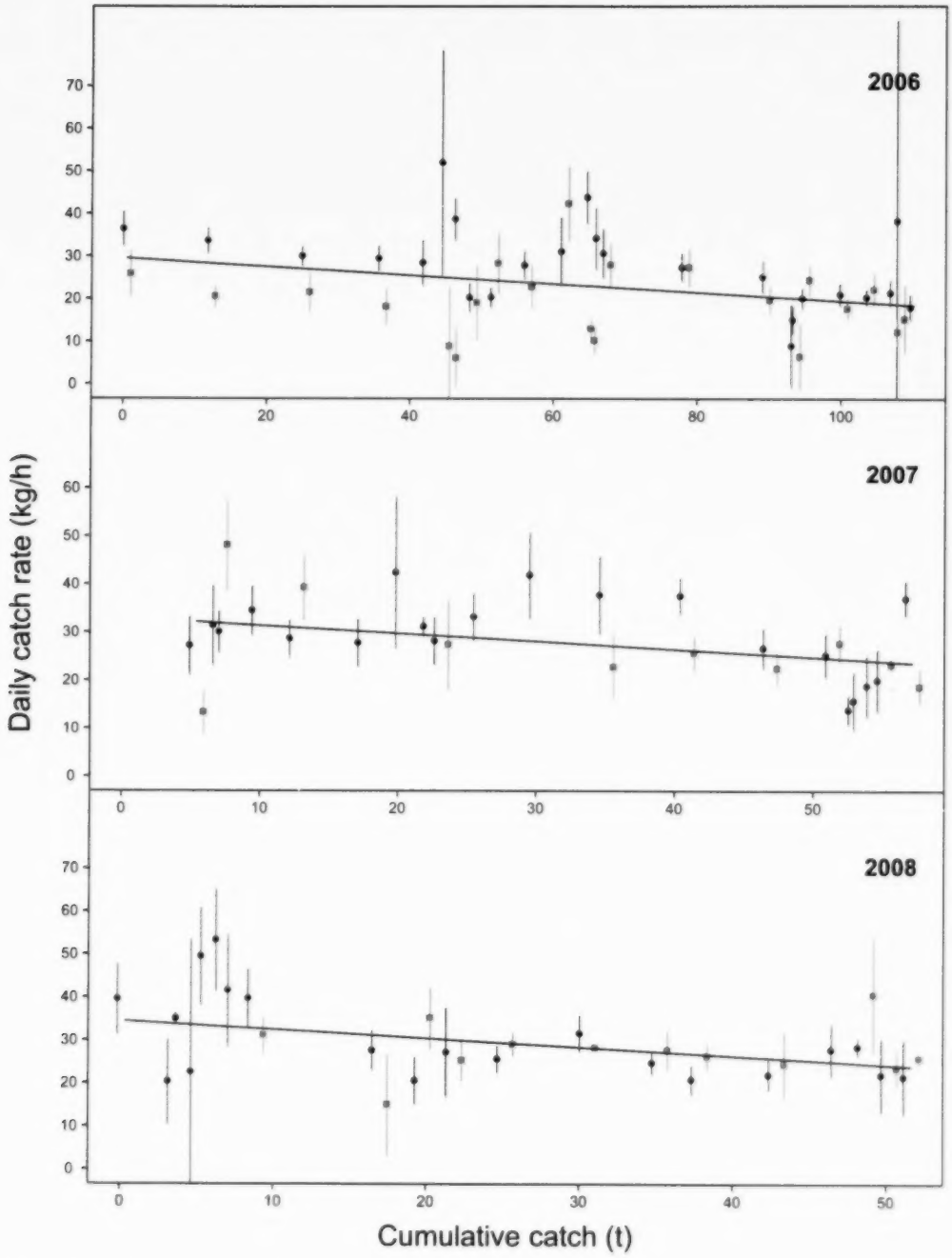

Fig. 13. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea C Scallop fishing area 29 for 2006 to 2008. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

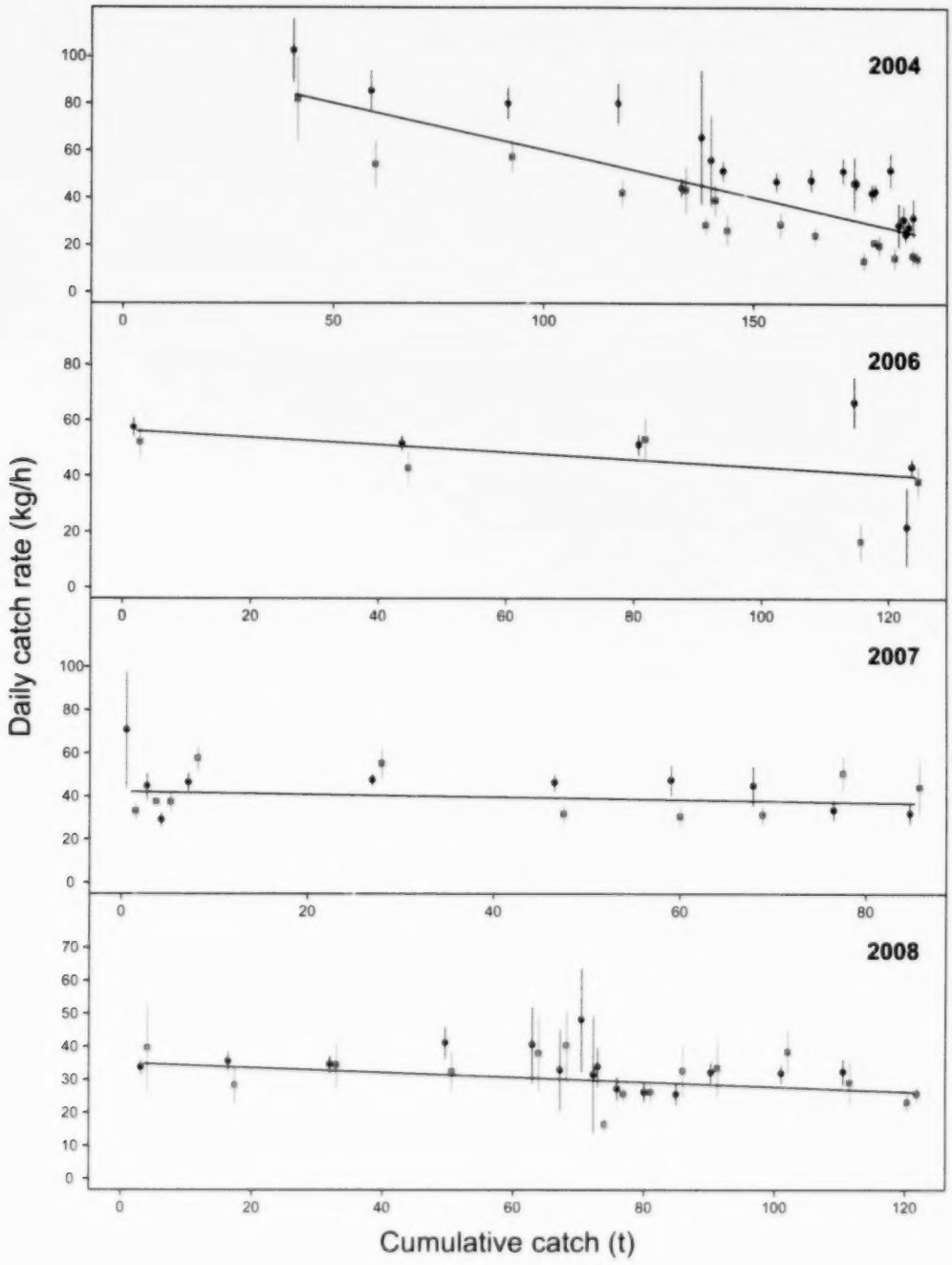

Fig. 14. Fit of depletion model to catch rate (kg/h) and cumulative catch for subarea D Scallop fishing area 29 for 2006 to 2008. Symbols: circle= Full Bay fleet, square = East of Baccaro fleet. ± one standard error indicated.

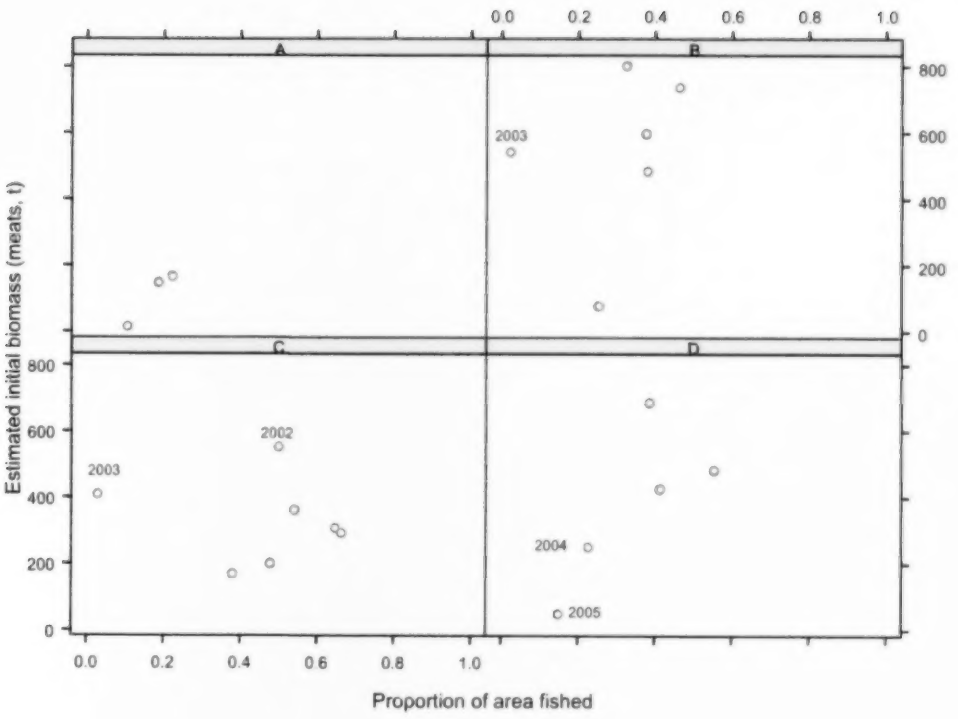

Fig. 15. Estimated initial biomass from the depletion model for each subarea in SFA 29 versus proportion of area fished determined from VMS data.

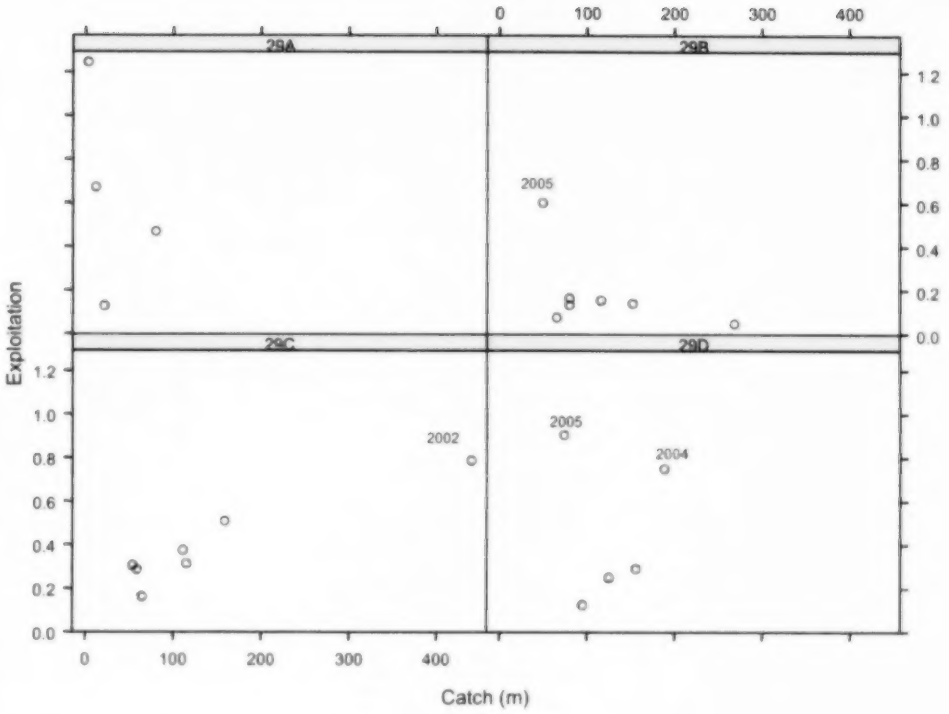

Fig. 16. Estimated exploitation from the depletion model for each subarea in SFA 29 versus catch for years 2002 to 2008.

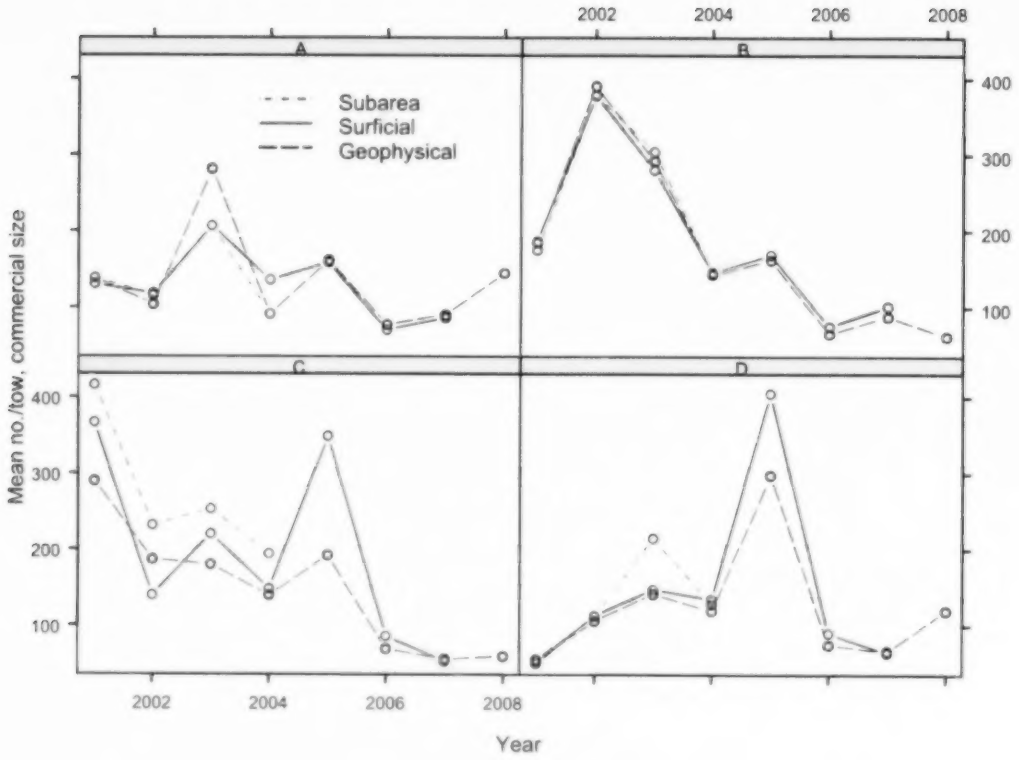

Fig. 17. Comparison of estimates of mean number per tow for the three survey designs used in Scallop Fishing Area 29 with the Full Bay Vessels.

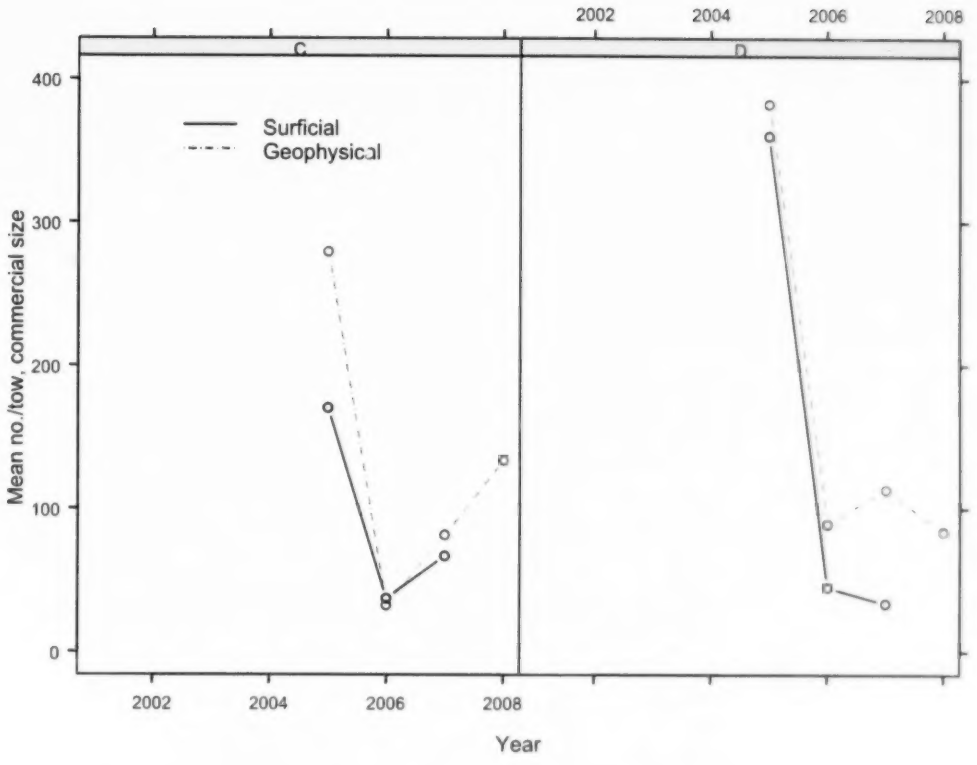

Fig. 18. Comparison of estimates of mean number per tow for the two survey designs used in Scallop Fishing Area 29 with the East of Baccaro Vessels.

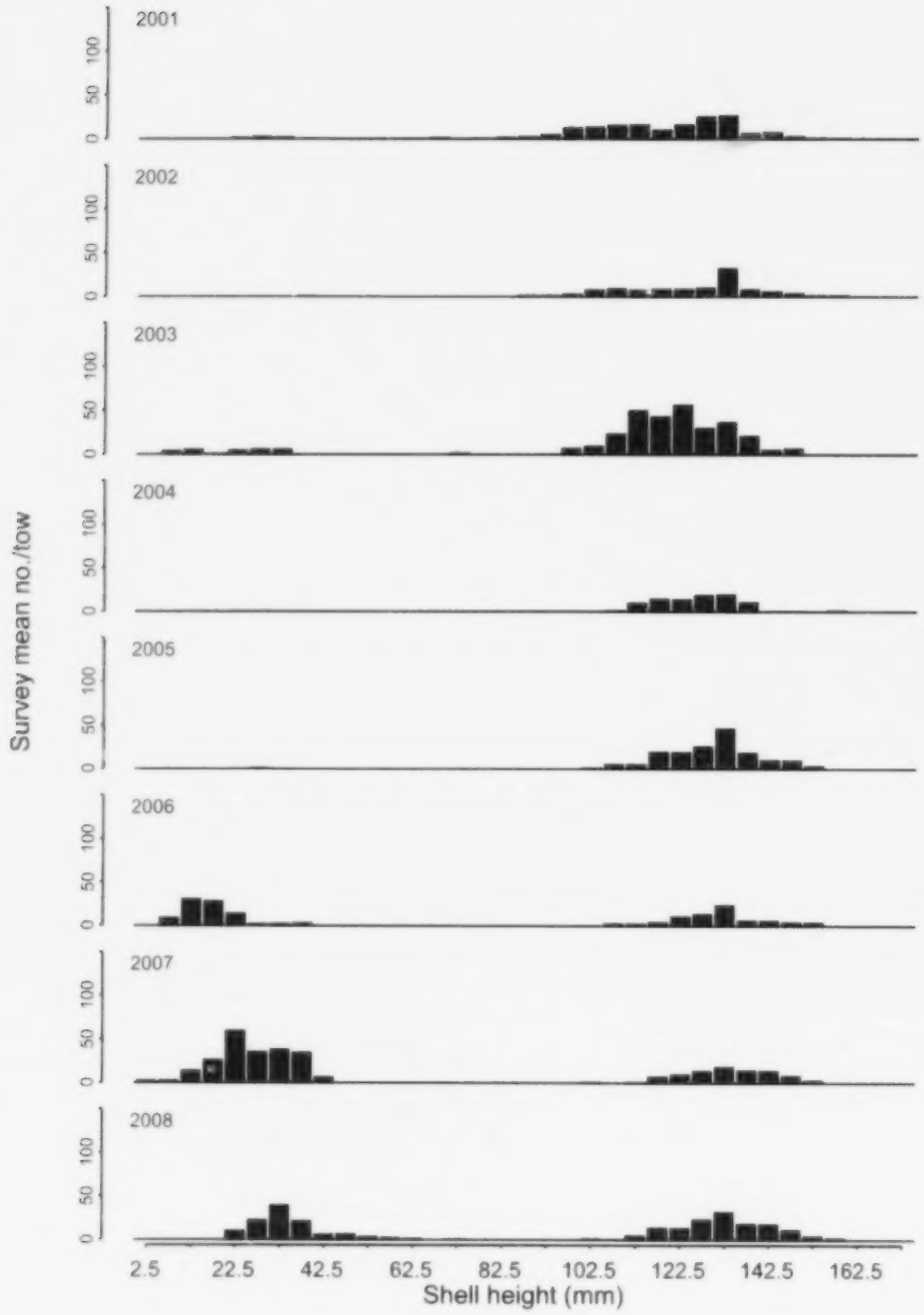

Fig. 19. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29A conducted by vessels from the Full Bay fleet.

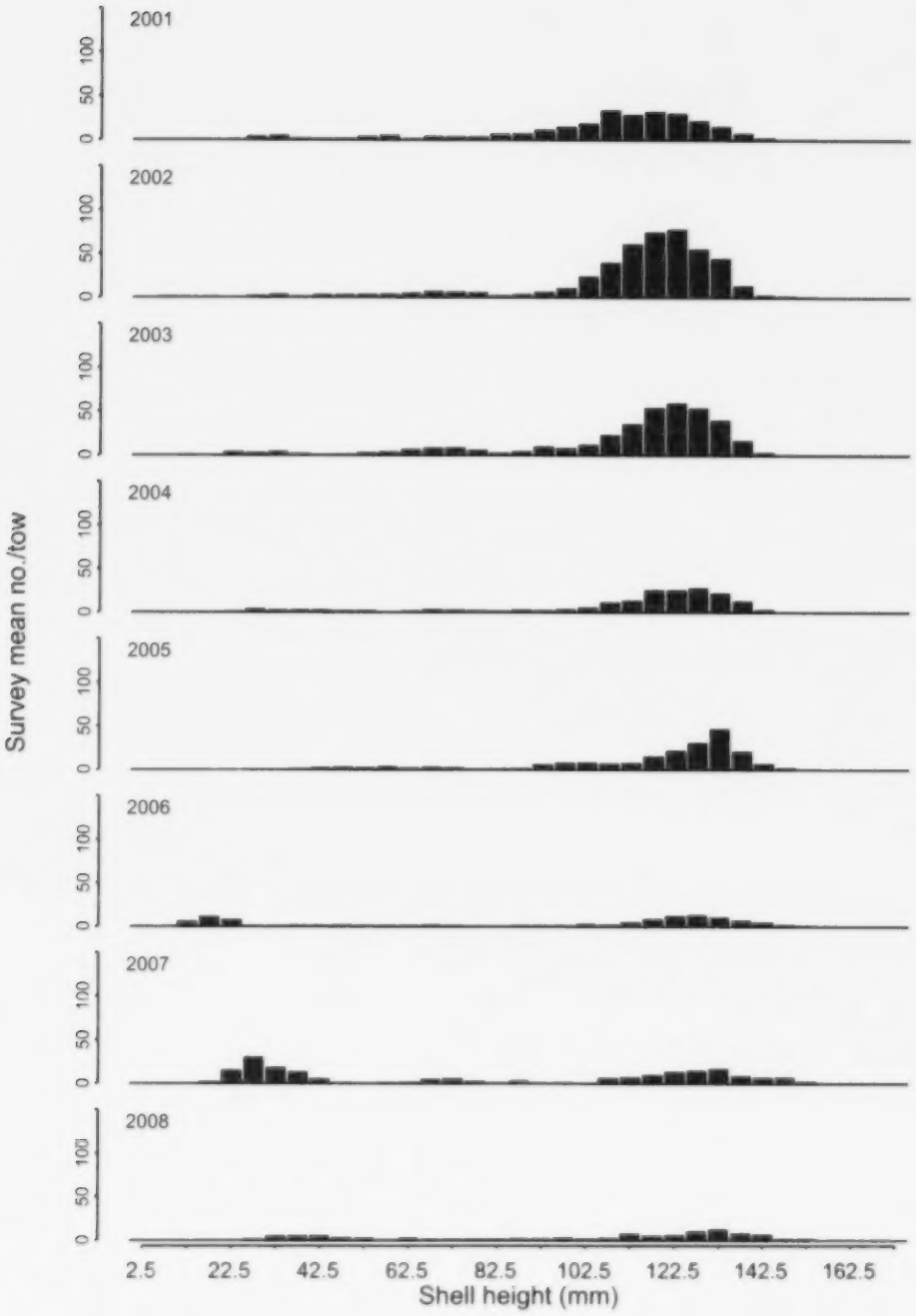

Fig. 20. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29B conducted by vessels from the Full Bay fleet.

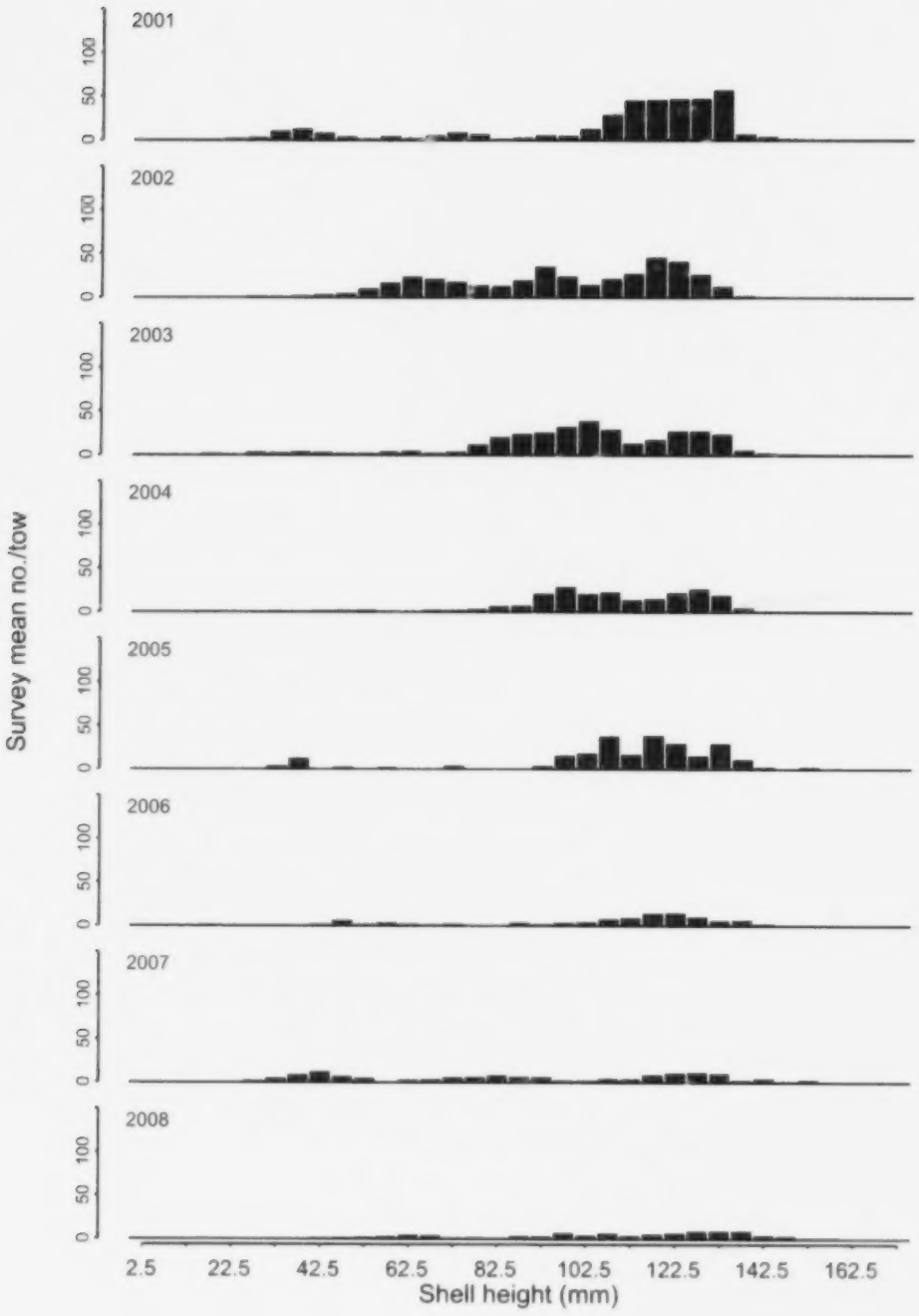

Fig. 21. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29C conducted by vessels from the Full Bay fleet.

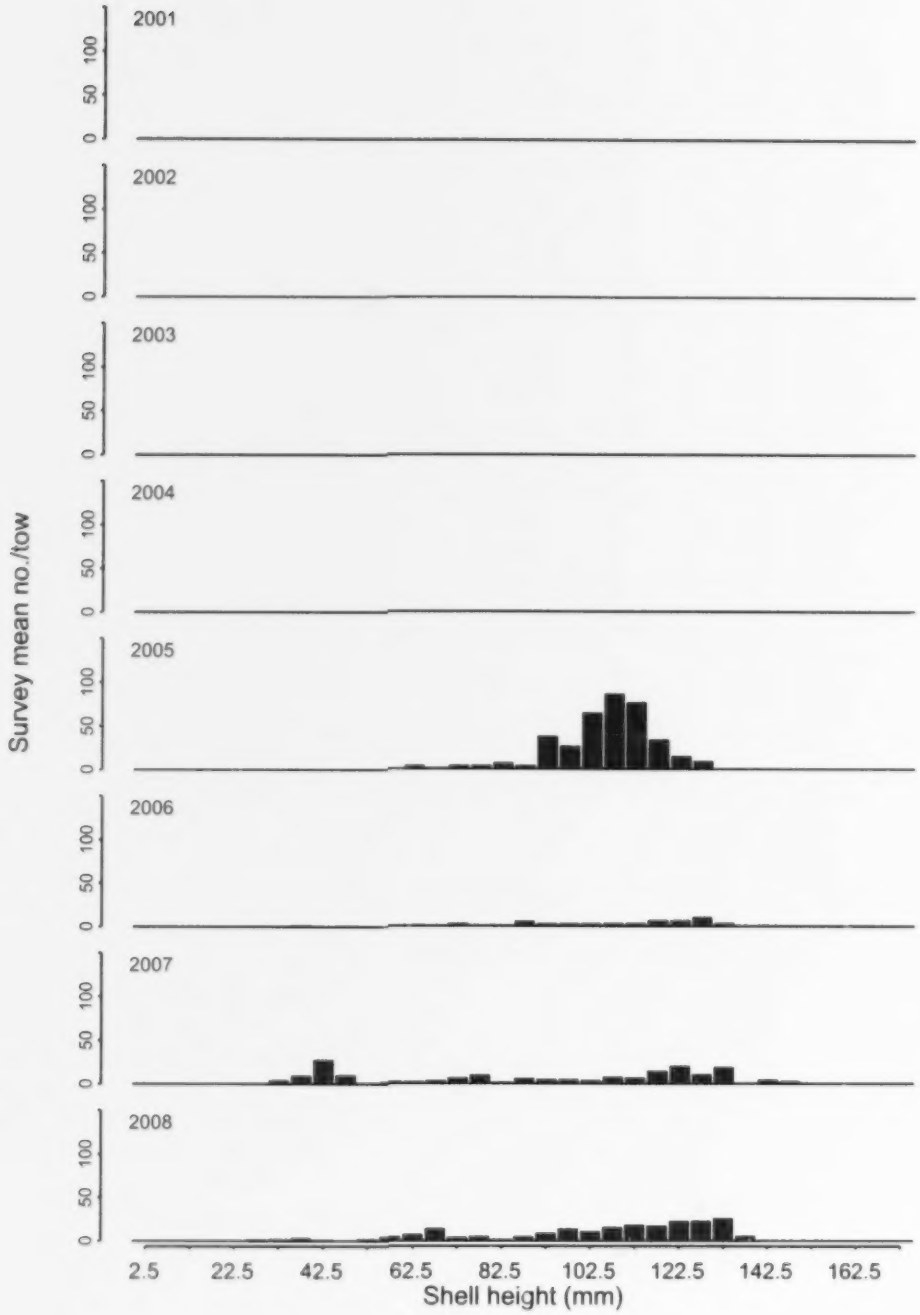

Fig. 22. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29C conducted by vessels from the East of Baccaro fleet.

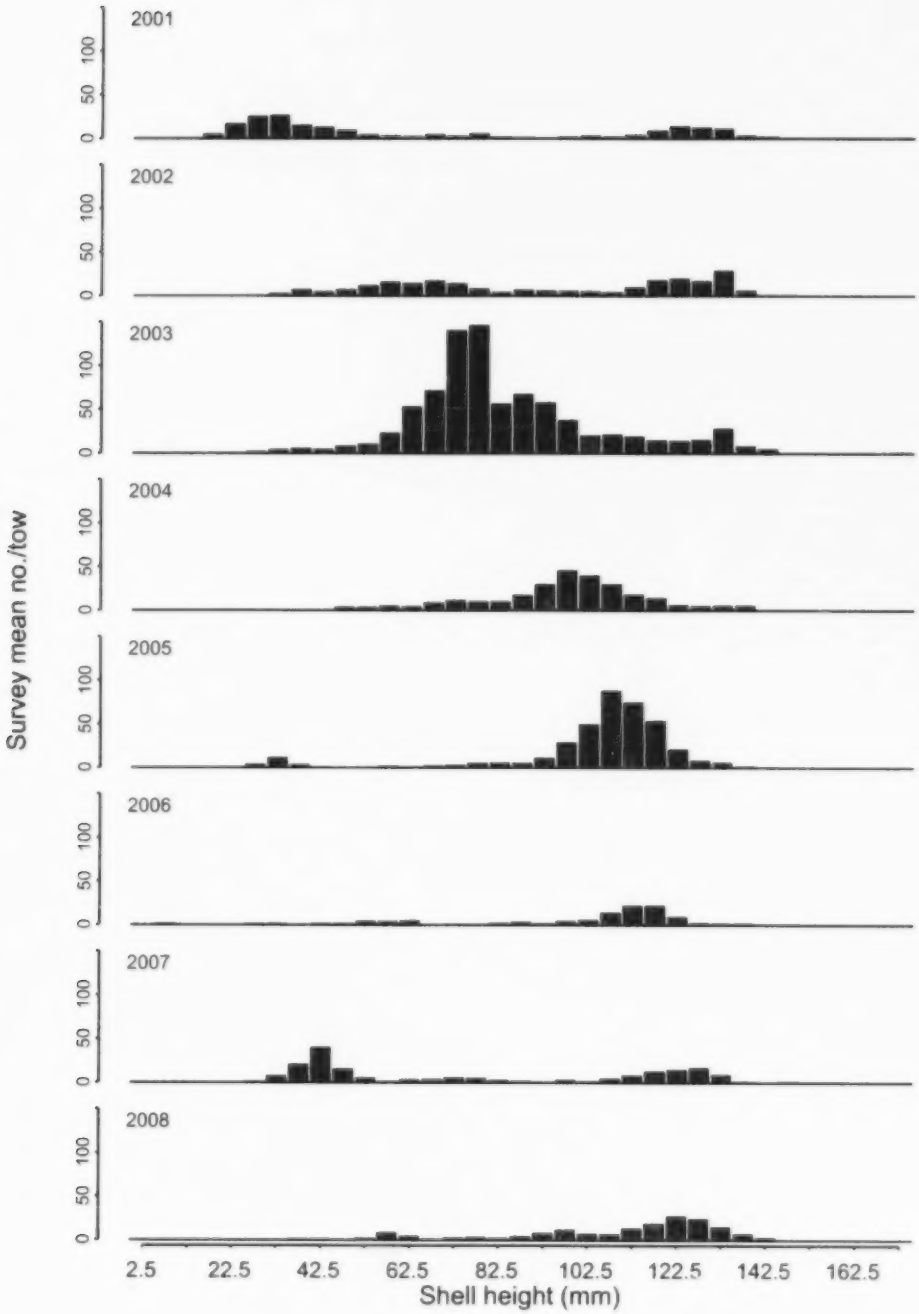

Fig. 23. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29D conducted by vessels from the Full Bay fleet.

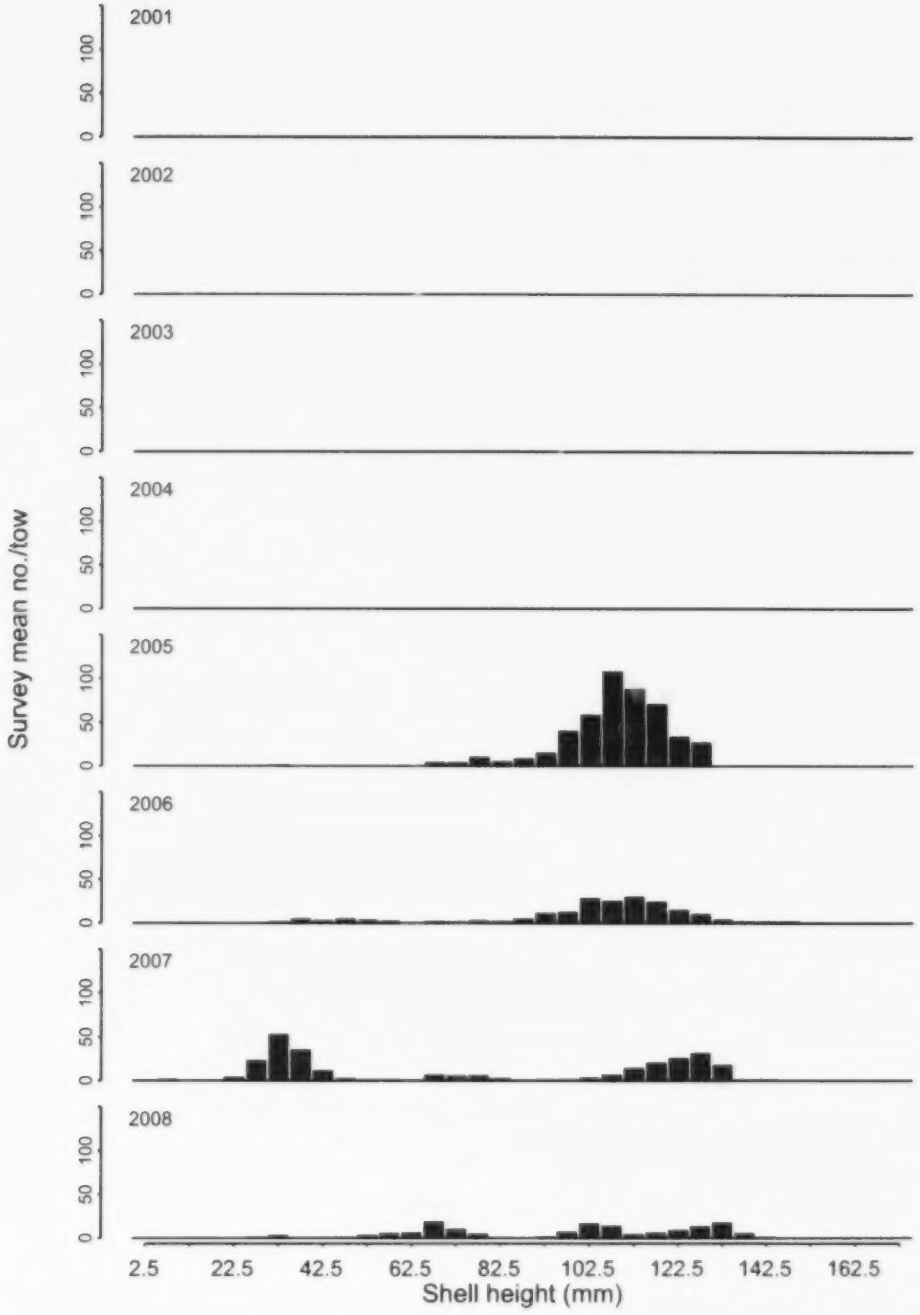

Fig. 24. Scallop shell height frequencies (mean number/tow) from the surveys in Scallop Fishing Area 29D conducted by vessels from the East of Baccaro fleet.

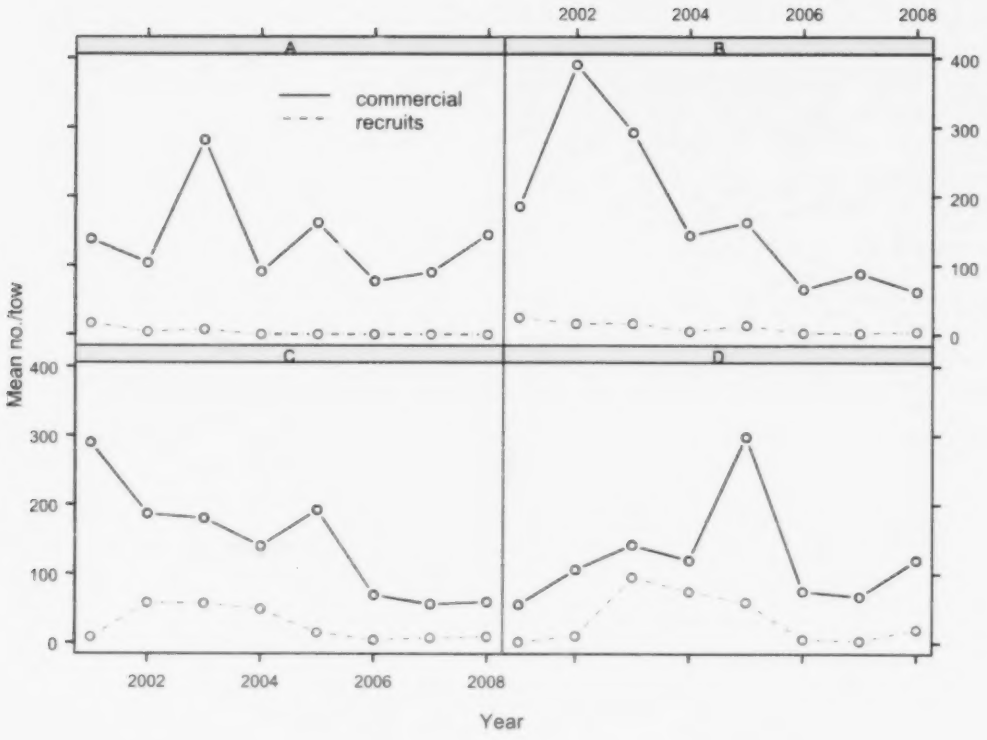

Fig. 25. Annual trends of fully recruited ($\geq$ 100 mm) and recruit (90–99 mm) size classes of estimates of survey abundance indices (numbers) from research surveys by subarea in SFA 29. Commercial and Recruits series estimated from F/V Julie Ann Joan (2001–2003, 2005–2008) and F/V Branntelle (2004) tows. Geophysical strata used for design.

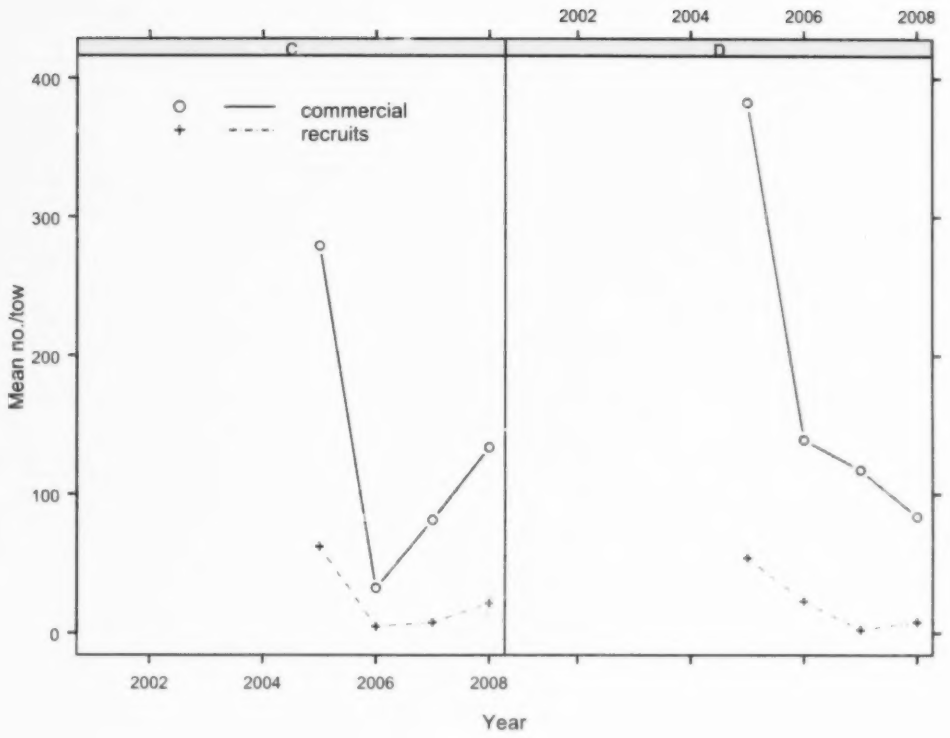

Fig. 26. Annual trends of fully recruited ($\geq$ 100 mm) and recruit (90–99 mm) size classes of estimates of survey abundance indices (numbers) from research surveys by subarea in SFA 29. Commercial and Recruits series estimated from F/V Overton Bay (2005)and F/V Faith Alone (2006–2008). Geophysical strata used for design.

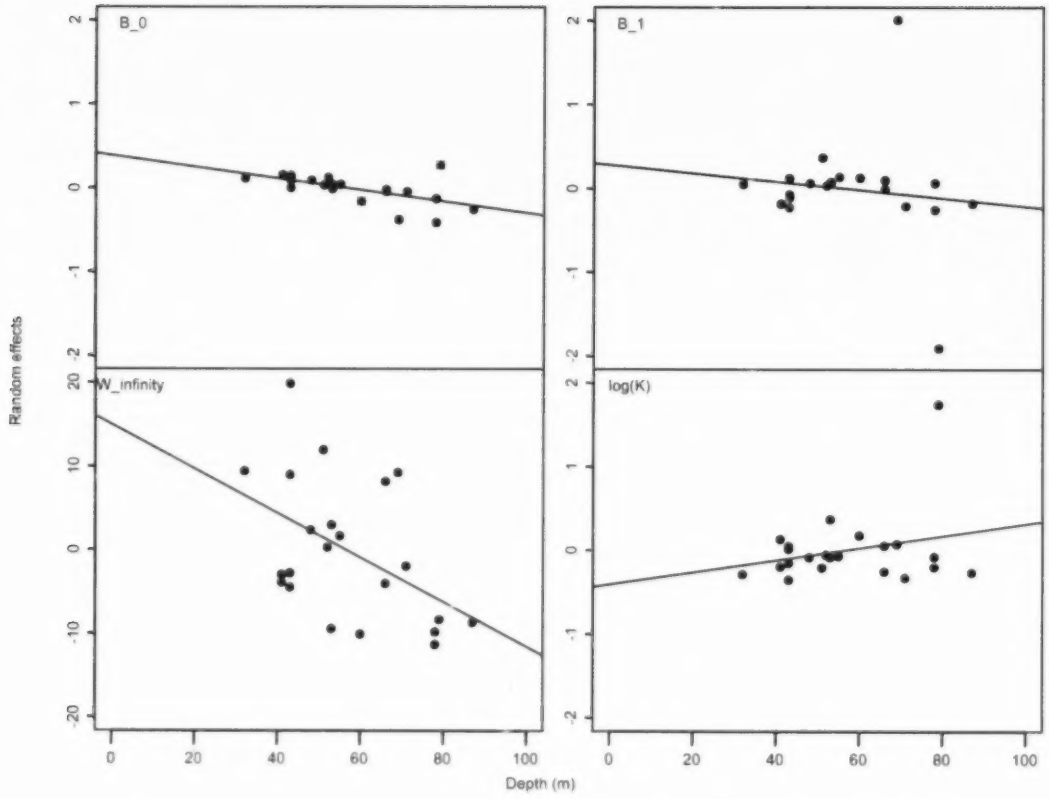

Fig. 27. Plot of random effects from the meat weight/shell height and meat weight/Age models versus depth (m) from 2008 survey of SFA 29.

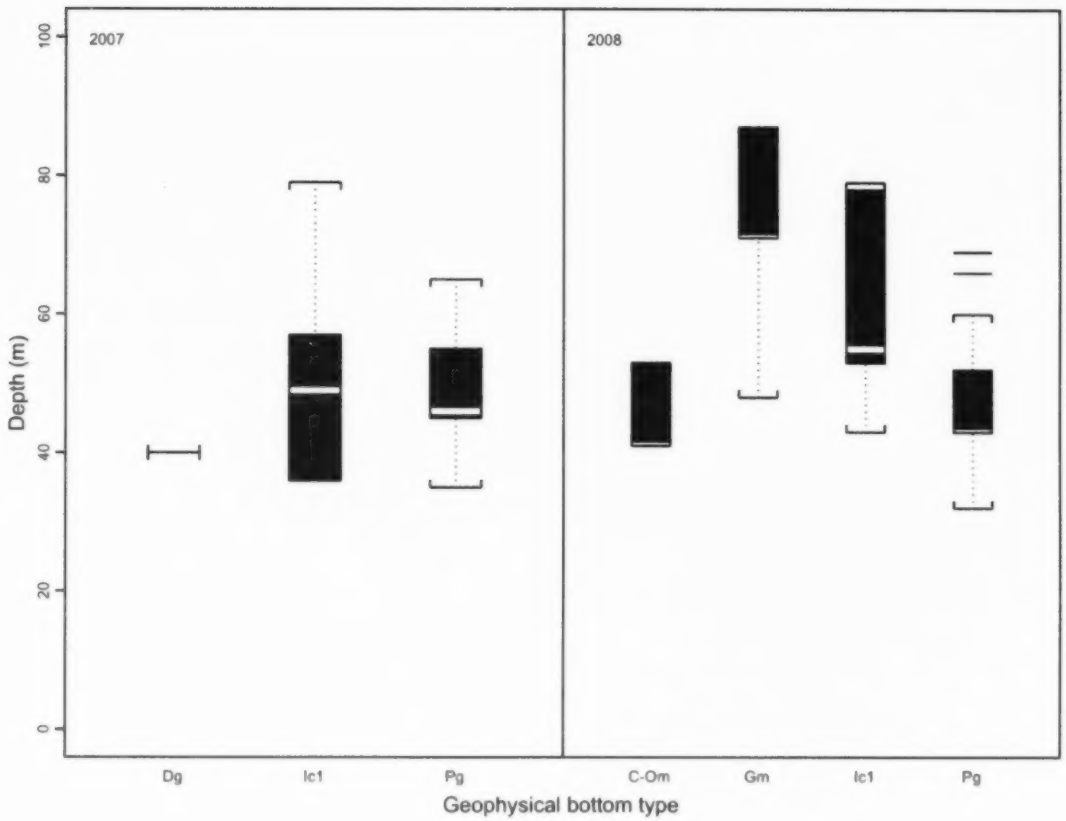

Fig. 28. Boxplots of the distribution of depths by geophysical bottom type for the detailed samples taken in the 2007 and 2008 annual survey of SFA 29.

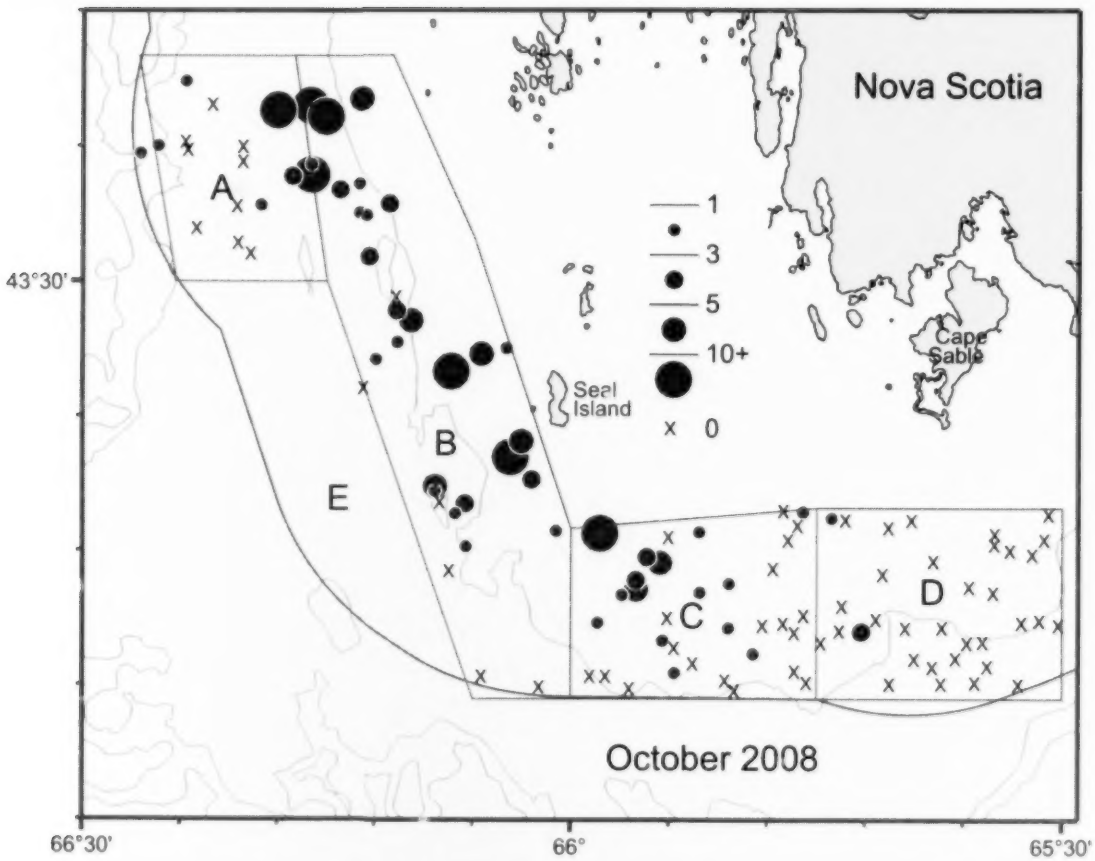

Fig. 29. Location and number of lobsters caught in SFA 29 during 2008 survey. Crosses indicate locations where no lobsters were captured.

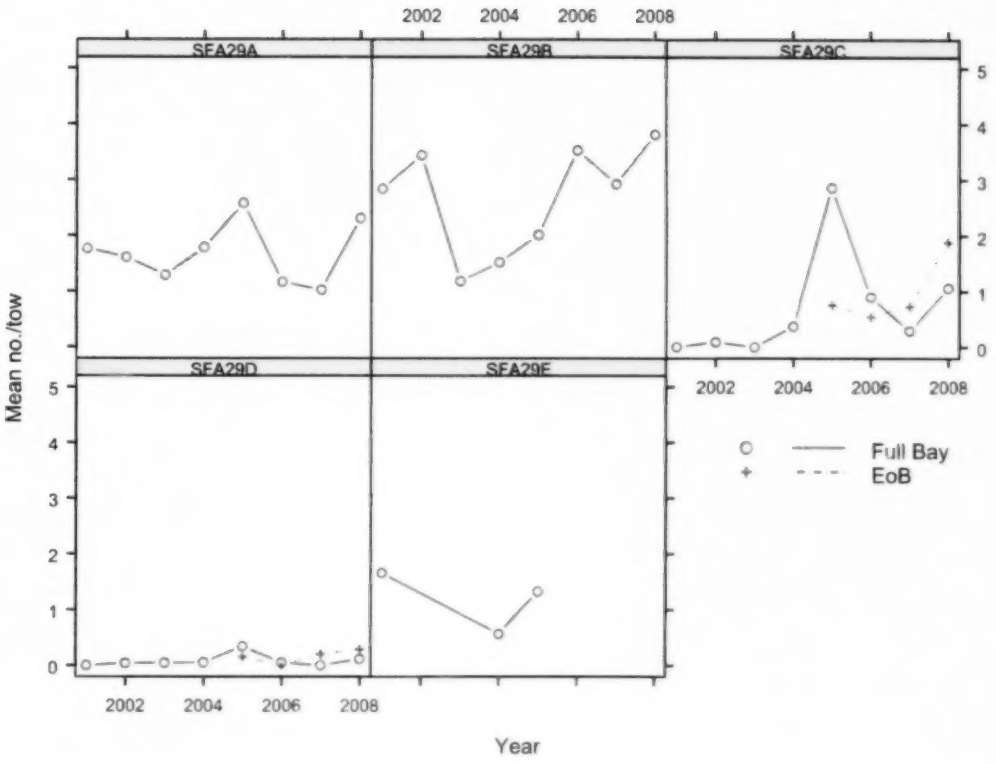

Fig. 30. Lobster number per tow from scallop survey. The two series for subareas C and D from 2005–2008 are for the different survey vessels (one from the Full Bay, one from the East of Baccaro fleet).

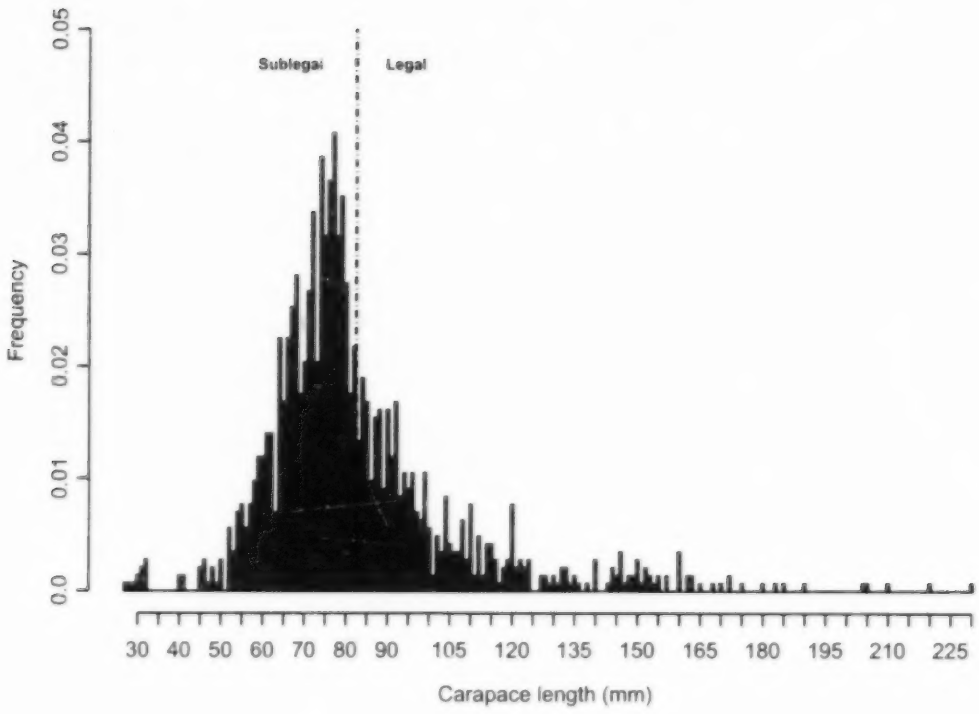

Fig. 31. Carapace frequency for all lobsters recorded by observers in the 2008 SFA 29 scallop fishery of subarea B.

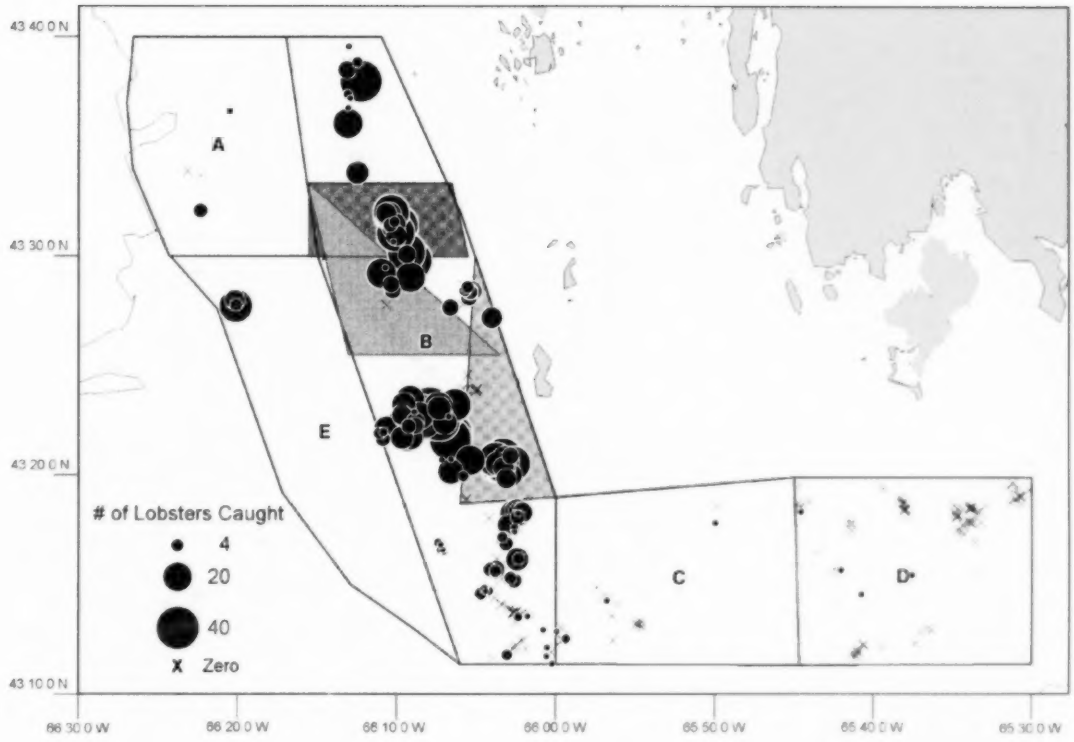

Fig. 32. Location and number of lobsters caught in SFA 29 during 2008 from observed scallop fishing trips. Crosses indicate locations where no lobsters were captured. Areas closed in subarea B during the fishery due to lobster bycatch indicated by the two upper polygons. The lower triangle (grey shading) was used in 2005 and 2006 to monitor lobster bycatch through mandatory observer coverage in the area.

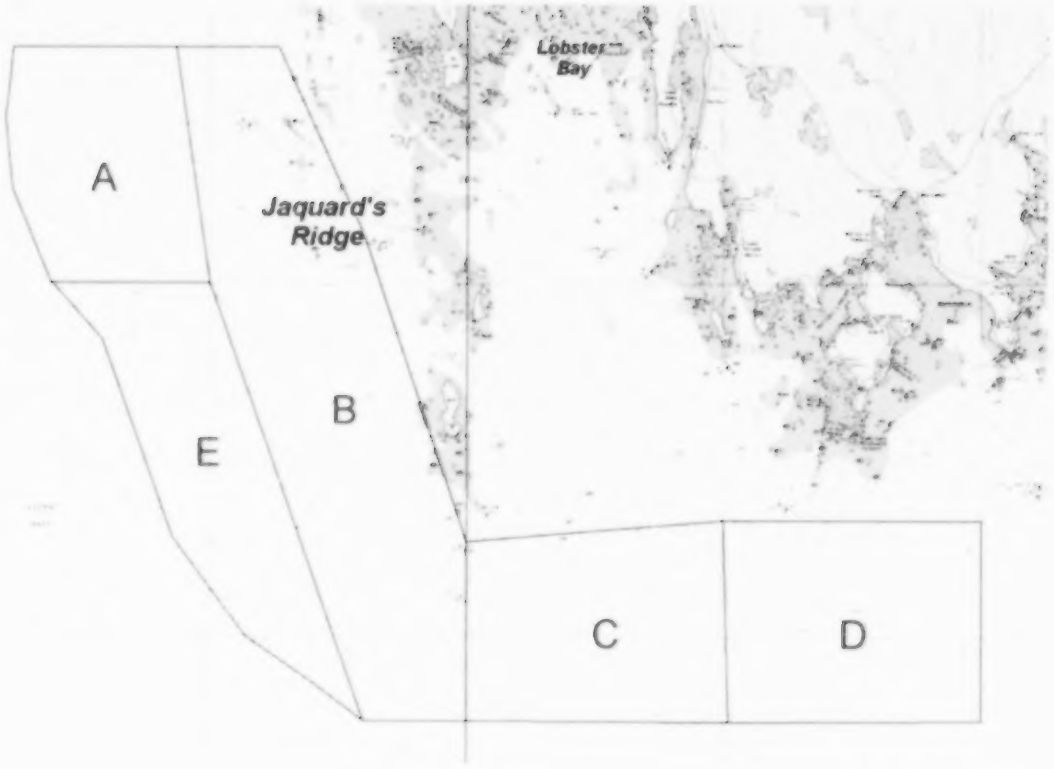

Fig. 33. Location of Jacquard's ledge in LFA 34/SFA 29.

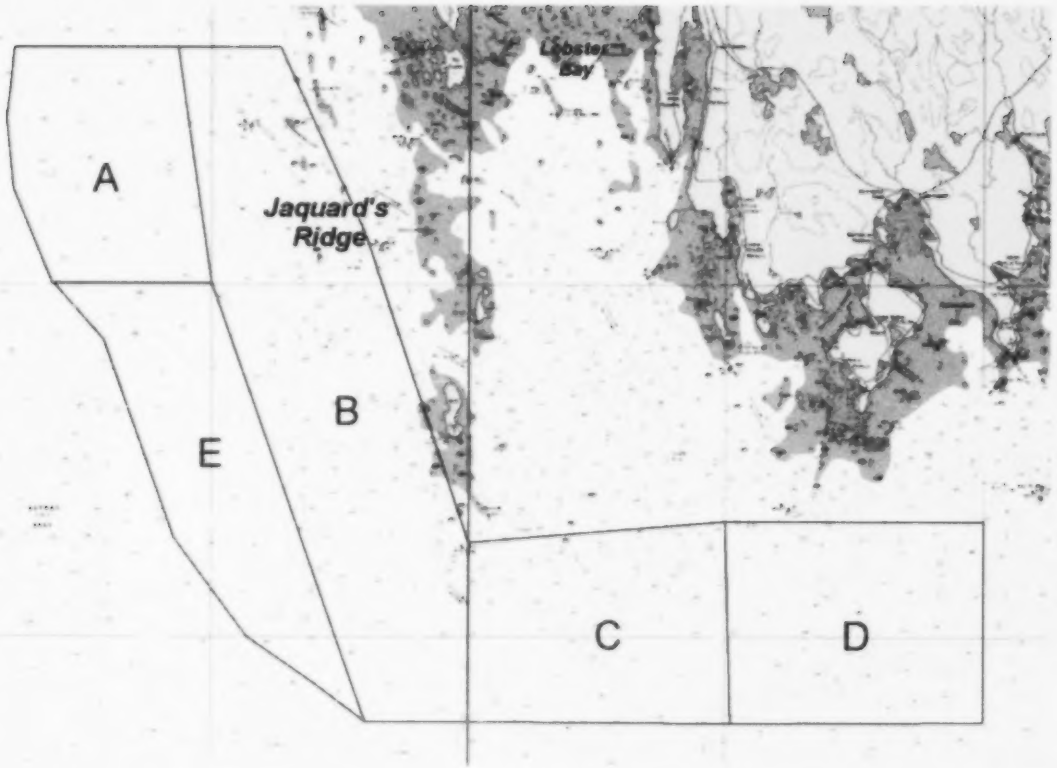

Fig. 33. Location of Jacquard's ledge in LFA 34/SFA 29.